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Environmental Assessment

Waste Treatment Facility

OWMC
Ontario
Waste Management
Corporation

A provincial crown corporation.

EVALUATION OF ALTERNATIVE DISPOSAL OPTIONS

Prepared for
The Ontario Waste Management Corporation

By

Gartner Lee Associates Limited

September, 1986

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September 26, 1986.

Dr. B.D. Mitchell,
Director,
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2 Bloor Street West,
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Toronto, Ontario.
M4W 3E2

Dear Dr. Mitchell:

Re: Evaluation of Alternative Disposal Options -
GLAL 84-F12

We are pleased to provide you with the finalized report for Stage 1 of the above noted study. Stage 1 consists of a review of existing literature and an investigation of existing experiences dealing with the hydrogeologic aspects of various methods of waste disposal. This study was undertaken in 1984 and the draft report provided to the Ontario Waste Management Corporation (OWMC) in February, 1985. At the request of OWMC the present report has essentially not changed from the 1985 draft version, except for correcting of typographical errors. Therefore it reflects the 1984 level of information and has not been updated to include more recent data or interpretations. Many of the Stage 2 studies recommended in this letter and the report have been undertaken by OWMC since 1985 to investigate in more detail various disposal options.

The disposal options discussed in this Stage 1 report are:

- deep well disposal,
- landfills,
- land treatment, and
- mine disposal.

Our work shows that landfills and mine disposal both merit further research in Stage 2. Deep well disposal and land treatment have serious constraints and further studies are not recommended.

We found that landfilling has been carried out world-wide and is the most common method of hazardous waste disposal. Thus, there is a great deal of practical experience with different landfilling procedures. In contrast, mine disposal, while theoretically viable, has not been commonly used for hazardous waste disposal, and there is less applicable experience. However, wastes are being stored in a mine in Germany and much research has been completed on the potential for using salt formations and salt mines for the disposal of radioactive wastes.

In dealing with the landfill option, we find that,

- active conventional engineered landfills,
- active, above-ground engineered landfills, and
- passive shallow entombed engineered landfills,

are all viable options when these facilities are located in deep, low permeability soil environments.

Mine disposal is feasible in the salt mines of southern Ontario. However, disposal in existing gypsum mines or mines located in the Precambrian rocks of southern Ontario is not recommended because of hydrogeologic conditions found at these mine sites.

If the landfills are constructed in thick low permeability soils, contaminant movement to underlying aquifers should be minimal. Some landfill designs may, however, pose the potential for leachate egress through surface springs on the sides of the fill and through the upper fractured zone of the soils. These conditions can be readily mitigated and monitored, resulting in perpetual care.

The concern of leachate migration is not as critical in the salt mine disposal options. This is because of the low permeability of the salt deposits, the resultant low quantities of ground water flux into the waste and their isolation from freshwater aquifers. There are, however, a number of concerns with this option. The mines are not designed for long term storage and there may be concerns with mine stability. Also, if remedial measures were required in the future they would be expensive due to the depth and inaccessibility of the rocks surrounding the mine after site closure. Another factor to consider is that the salt mine disposal option offers no flexibility in siting, i.e. the mine locations are fixed. And finally there is only limited experience in the use of these facilities for hazardous waste disposal.

Our first recommendation is that factors other than geology and hydrogeology should now be studied for the mine disposal option. These other factors might include transportation, economics, social impact, operations, atmospheric dispersion, etc. Once these factors have been integrated with this present study, and if a decision is made to continue the evaluation, then more detailed hydrogeologic, geological and geotechnical studies should be initiated.

Our second recommendation is that further hydrogeologic studies should be undertaken for the landfill options, separately from the mine disposal option.

Finally, we recommend that no further work be done on either the deep well disposal option or the land treatment option.

The following report is in two volumes. Volume 1 contains an extensive executive summary, descriptions of assumptions and methodologies, discussions of our findings, references, and a bibliography. Volume 2 is separate and contains the report on disposal practices in the United States prepared by Geraghty and Miller, Inc. on behalf of OWMC.

We thank you for this opportunity to once again be of service to OWMC.

Yours very truly,

GARTNER LEE ASSOCIATES LIMITED

Grant Anderson

E.G. Anderson, P.Eng.,
Project Director.

GWR:jcm

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STUDY TEAM

This report was prepared under the overall direction of E.G. Anderson, P.Eng., Project Director and G.W. Reynolds, M.Sc., Project Manager. Major contributing authors were:

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- N.M. Woerns

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VOLUME 1

EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

- To evaluate alternative disposal options for OWMC's wastes and treated waste residues based on hydrogeologic and geologic perspectives with some consideration of preliminary geotechnical and preliminary regulatory aspects (Stage 1 Studies).

- To identify from the potential disposal options what OWMC should consider for further evaluation in Stage 2 studies.

SCOPE

- The following disposal options were considered;

  (i) Deep well disposal (page 15),

  (ii) Land treatment (page 87),

  (iii) Active Conventional engineered landfill (page 55),

  (iv) Active above-ground engineered landfill (page 62),

  (v) Passive deep entombed engineered landfill (page 68),

  (vi) Passive shallow entombed engineered landfill (page 74),

  (vii) Disposal in existing mines in Precambrian rocks (page 95),

  (viii) Disposal in existing mines in Paleozoic rocks (page 107).

- The evaluation contained in this report has been a "desk top" generic study only; i.e. only published literature, available unpublished data and discussions with various people and regulatory agencies knowledgeable about these disposal approaches have been used as the information base for the evaluation.

METHOD

- The information collected was assessed qualitatively to determine what the advantages and disadvantages of each disposal option were in a generic sense from hydrogeologic, geologic, geotechnical and regulatory perspectives.

- The hydrogeologic advantages and disadvantages of each option related to such factors as (1) hydrogeologic feasibility, (2) ability to minimize impact on ground water and surface water resources, both naturally and with the use of active contaminant control systems, (3) reliance on active systems and long term maintenance, (4) predictability of contaminant migration, and (5) ability to monitor.

- The geologic advantages and disadvantages of each option related to such factors as (1) geologic uniformity and predictability, (2) geologic stability, (3) geologic complexities as they relate to contaminant migration and (4) interferences with geologic resources.

- The geotechnical advantages and disadvantages of each option related mainly to stability and construction feasibility concerns.

- The relative importance of these advantages and disadvantages were then qualitatively assessed to determine which options had potential as hydrogeologically, geologically and geotechnically viable disposal alternatives for OWMC to evaluate further in Stage 2, and which options had potential constraints.

PREMISES

Premises are the information or restrictions on scope provided by OWMC or by other studies undertaken by the Corporation which have been taken as points of departure and treated as given.

- The comparative evaluation will be qualitative and generic based on existing published information and will consider mainly hydrogeologic and geologic aspects with some consideration of geotechnical and regulatory aspects.

- At the request of OWMC untreated wastes were considered for some options as well as treated wastes.

- The waste characteristics are assumed to be as follows:

  (1) treated liquids: 32,000 to 192,000 m³/a of a brine-like inorganic solution (page 11),

  (2) treated solids and sludges: up to 420,000 m³/a of a relatively inert, inorganic residue (pages 9 and 12), and

  (3) untreated wastes: a wide variety of types and volumes of liquids, solids and sludges of either inorganic or organic nature (page 13).

- All disposal options are assessed for southern Ontario only.
- Deep well disposal is considered in the Cambrian formations only.
- Deep well disposal is limited to liquids only.
- No liquids or untreated wastes will be placed in a landfill.
- All landfill designs are assumed to be located in the same hydrogeologic environment of thick, fine grained soils of low permeability.
- Only existing mined space was assessed.

POSTULATES

Postulates are any assumptions or hypotheses made at the outset that are basic to the study approach. The postulates were discussed with and developed in conjunction with OWMC.

- For this study the primary objectives of a potentially viable disposal option are;

  (1) that it is hydrogeologically and geotechnically feasible,

  (2) that it minimizes impact on ground and surface water resources, and

  (3) that it minimizes risk to human health.

- Liquids or leachate emanating from any of the disposal options are considered to be contaminated regardless of waste treatment.

- Deep well disposal is assessed for both treated and untreated liquids.

- Landfilling is assessed for treated waste residues only in solid or sludge form that are not solidified.

- Operationally land treatment can be undertaken by irrigation or landfarming. Irrigation is assessed for treated liquids only and landfarming for treated and/or untreated sludges only.

- Mine disposal is assessed for both untreated and treated wastes in either fluid or solid form.

- Mine disposal is evaluated for natural containment only.

STATUS OF DATA

- Data sources used in this study were; published literature from Canada, the U.S.A. and Europe, discussions with Ontario and U.S.A. regulatory agencies and 'experts' knowledgeable in the disposal options, unpublished data from OWMC, Gartner Lee Associates Limited and Geraghty and Miller, Inc. files and, where available, unpublished data from regulatory agencies and private sources in Canada and the U.S.A.

- Relative confidence was placed on the information available from published literature, since these works have usually been subject to quality control and peer review. However, it is only recently that evaluations of alternative disposal options have been undertaken; only one evaluation similar to this one was identified in the published literature. Consequently, much of the information available in the literature has not been derived for use in an evaluation and therefore is subject to interpretation.

- The quality of the unpublished data (such as the data on landfills collected by Geraghty and Miller, Inc. from the landfill operators) was not subjected to an independent evaluation, therefore the possibility of incorrect or incomplete data imposes limitations on any calculations or conclusions drawn from this information.

- There is a significant lack of published and accessible unpublished hydrogeologic information on existing mines in Ontario and on deep well disposal in the Cambrian formations of Ontario.

- There is a lack of information from Canadian experiences for most of the disposal options.

- There is a general paucity of literature and field data on the performance of the mine disposal option, above ground engineered landfill option and the deep entombed engineered landfill option, since these concepts are relatively new. As well, long term performance data are not available on state-of-the-art designs for passive and active landfills and their active systems because the state-of-the-art landfills are all less than 10 years old.

- There are uncertainties about the assumed waste volumes and characteristics; variations in these values could change the study results because, for example, the practicality of deep well disposal is volume and chemistry dependent and the practicality of the caisson-hole entombed landfill is volume dependent.

- The data has been assessed qualitatively and generically only, therefore site specific data and more detailed generic evaluation such as computer modelling may affect interpretations.

MAIN FINDINGS

For deep well disposal, the main findings are;

- Disposal of all of the untreated liquids does not appear practical at this time. The chemical variability of these wastes indicates there is significant potential for waste/formation water incompatibility, clogging and well degradation. (page 35)

- Disposal of treated liquids is marginally practical given the liquid volumes expected from the OWMC facility. Due to the moderate permeabilities and thin nature of the Cambrian, disposal will probably be limited to the lower limit of expected liquid volumes (~1 L/s). Some permeable zones capable of handling larger flows do exist but their prediction before drilling and testing is unlikely. (page 35)

- Given this limited practicality, the lack of geologic and hydrogeologic data and the uncertainty about contaminant migration, deep well disposal does not appear to be a preferred disposal alternative at this time. However, if liquid volumes can be reduced and comprehensive subsurface testing is carried out this may become a viable option for future consideration.

For the four landfill design alternatives, the main findings are;

- The major hydrogeologic concerns associated with landfilling in low permeability deposits in Ontario are leachate springs and, to a lesser extent, lateral movement of leachate in the shallow ground water of the fractured zone. These can potentially lead to surface water contamination or direct human or animal contact with leachate. (page 46)

- Contamination of underlying ground water resources is less of a concern because it is assumed all designs will be underlain by a sufficiently thick sequence (depth is site specific) of unfractured low permeability soils. Contaminant flow rates and fluxes are very small in these soils and attenuation capabilities are high. (page 49 & 50)

- From the two points above, the hydrogeologic viability of the landfill designs is dependent on their ability to minimize leachate springs and, to a lesser extent, leachate movement into the fractured zone.

- From a hydrogeologic perspective, the active conventional engineered landfill, the active above ground engineered landfill and the passive shallow entombed engineered landfill, when located in low permeability soils, minimize the concerns above and therefore all appear to be potentially viable disposal options for OWMC's treated waste residues. Each of these landfill configurations have their own hydrogeologic advantages and disadvantages which are discussed in the conclusions below. (pages 53, 62 & 74)

- Future deterioration or failure of the active systems in either the active conventional engineered landfill or the above ground engineered landfill design may result in leachate springs and an input of leachate to the fractured zone. Consequently, these landfills will probably require long term maintenance. On the other hand, while the active systems are functioning, escape of leachate at surface or into the surrounding soils will be minimal. Continued operation of these systems for as long as possible,

  (1) allows leachate to be collected and treated, if required, before release to the environment,

  (2) may provide sufficient time for the waste mass and leachate strength to decay, and

  (3) may delay release of contaminants until new technologies are available for further processing of the treated waste residues should this need arise. (pages 53 to 67)

- With the shallow entombed landfill, there is a potential for some leachate diffusion into the fractured zone and possibly to surface. However, this diffusion would be very minor and would be much less than would occur upon failure of the active conventional engineered landfill or the above ground landfill designs. If the potential for leachate impact from the shallow entombed landfill is determined to be small because of the small amounts released, then this landfill design may reduce the need for long term maintenance. If leachate impact is a concern, the back-up leachate collection system can be used to operate the design as a modified active landfill design. (pages 74 to 79)

- The deep excavated entombed engineered landfill may have limited practicality due to potentially serious geotechnical concerns such as bottom upheaval and slope stability. The seriousness of these concerns will be site specific. If, based on site specific information, no geotechnical constraints are identified then this landfill design may be a potentially viable disposal option for OWMC's treated waste residues. (page 72)

- Based on the assumed treated waste residue volumes the caisson hole approach to the deep entombed engineered landfill does not appear practical due to the large number of holes required. However, if treated waste residue volumes can be substantially reduced this method offers equivalent containment to the deep excavated entombed engineered landfill without the associated construction concerns. (page 71)

- None of the four designs were limited by regulations of the Ontario Ministry of the Environment provided it could be shown they worked on a site specific basis. The Ministry of Environment did, however, express concerns about the deep entombed engineered landfill designs because (1) they may not be practical, (2) they are unproven in practice and (3) they place wastes deeper towards underlying aquifers than the other designs. (page 79)

- Co-disposal within an existing municipal landfill has the advantage of using the existing landfill as a case history to determine landfilling impacts. However, the following are considered significant constraints to co-disposal as a viable option; (1) differences in siting, operating and engineering criteria between OWMC and the existing landfill, (2) potential incompatability between some municipal wastes and the treated waste residues, (3) changes in leachate chemistry that may require treatment of all leachate, even that produced by the domestic waste and (4) the need to find an existing site presently large enough to accept both municipal waste and OWMC's waste residues. (page 80)

For land treatment, the main findings are:

- For specific waste streams land treatment is a viable disposal option that should not pose concerns to surface water or ground water resources. (pages 89 to 94)

- The specific wastes streams that have potential for land treatment are the highly biodegradable fractions of the untreated wastes. These are estimated to be less than 25% of the total wastes being accepted by OWMC. Therefore land treatment is a partial disposal option only. (pages 89 to 94)

- The treated wastes, and portions of the untreated wastes are inorganic and therefore cannot be disposed of by land treatment. (page 91 & 92)

- Ontario regulations require that an experimental application plot be field tested prior to approval of a land treatment site to show the waste is degradable and does not pose a risk to surface or ground waters. (page 91 & 92)

- Land treatment operations in Ontario are restricted by cold, snow and wet weather to about 100 to 120 days of application. Storage facilities are required at other times of the year. (page 91)

For disposal in existing mines, the main findings are:

- Ontario Provincial laws and guidelines encompassed under the Ministries of Environment, Labour and Natural Resources do not preclude mine disposal as an option.

- There are hydrogeologic constraints associated with the use of Precambrian mines as a disposal alternative for OWMC's wastes. These constraints are the uncertainties associated with ground water flow in fractured rock, poor geologic and hydrogeologic predictability, poor natural containment, requirement for active systems and perpetual care, proximity to aquifers and difficulty for monitoring. (page 103)

- There are hydrogeologic constraints associated with the use of Paleozoic gypsum mines as a disposal alternative for OWMC's wastes. These are the uncertainties associated with poor isolation from known shallow aquifers, dewatering problems, requirement for active systems and perpetual care and often poor mine stability. (page 127)

- Hydrogeologically, existing mines in the Paleozoic salt beds of the Salina Formation appear to have potential as waste repositories. However, concerns about mine stability, future disturbances by humans and mineral resource mining restrictions would have to be resolved. (page 122)

- Hydrogeologically and geologically the Goderich salt mine appears to have several advantages over the Ojibway salt mine. (page 127)

- It should be emphasized that the identification of preferred disposal options in this study has been based on qualitative assessment of hydrogeologic, geologic, preliminary geotechnical and preliminary regulatory factors only. There may be other over-riding factors that alter these conclusions. The final determination of preferred disposal options cannot therefore be ascertained until all aspects have been assessed and compared in the Stage 2 studies.

RECOMMENDATIONS

- Factors other than those considered in this analysis should be integrated with these results to further refine our conclusions on the salt mine disposal option. Examples of these other factors are transportation, economics, social impact, operations, atmospheric dispersion, etc.

  Once the other factors have been integrated with these findings, those disposal options remaining should be assessed in more detail. The following recommendations are presented as an indication of the kinds of Stage 2 hydrogeologic, geologic and geotechnical assessments required.

- The volumes and chemistry of the treated liquid wastes should be determined more exactly, to check on the practicality of deep well disposal.

- If it is possible to provide enough reduction in liquid volumes to make deep well disposal more practical, this disposal option should be assessed further and compared to other modes of liquid disposal, i.e. discharge to an acceptable receiving water body or existing sewage treatment facility or total solidification.

- The active conventional engineered landfill, the active above ground engineered landfill and the passive shallow entombed engineered landfill should all be considered for further evaluation in Stage 2 studies.

- Considerable evaluation has already been completed on landfilling as a disposal option, especially with respect to locational aspects. However, from a hydrogeologic and geotechnical perspective further evaluation of the landfill designs in Stage 2, to aid in specific design decisions, should include:

  1) both generic and site specific hydrogeologic modelling of each design,

  2) hydrogeologic modelling of various active systems, both generically and with site specific input,

  3) a more complete hydrogeologic and geotechnical evaluation of active system designs and the reasons for their success or failure in general terms and based on site specific information, and

  4) collection of detailed monitoring and performance data from company or government files to evaluate the performance of various existing landfill designs in humid climates and low permeability soils.

- The volumes of treated solids should be determined more exactly, to check on the practicality of the caisson-hole entombed landfill.

- If it is possible to reduce the volume of treated waste residues such that the caisson hole method is practical, then this design should be evaluated further.

- If site specific information does not identify major geotechnical constraints to the excavated deep entombed engineered landfill, then this design should also be included for evaluation in Stage 2 studies.

- The viability and value of land treatment as a disposal option for specific types of biodegradable untreated wastes be assessed with respect to other treatment alternatives such as incineration.

- If, after assessing the other factors (i.e. transportation, engineering, economics, social impact etc.) salt mine disposal appears feasible, further hydrogeologic, geologic and geotechnical evaluation of the salt mines should include:

  1) contacting the existing mines to obtain previously unavailable geology and hydrogeology information,

  2) an inspection of the mines and discussion with mine staff by experienced geologists, hydrogeologists and mine engineers,

  3) an inspection of existing core information from the vicinity of the salt mines by a study team of geologists and hydrogeologists, and

4) meeting with representatives of the radioactive waste research programs in North America and Europe to determine the state-of-the-art in salt mine disposal research.

- Consideration should be given to undertaking the Phase 2 geologic, hydrogeologic and geotechnical evaulations in parallel with studies of other factors.

- The Ontario Ministry of Labour should be involved in any evaluation of proposed underground work as sections of the Mine Occupational Health and Safety Act and Mine Regulations will govern parts of the work program, and any future disposal operation.

1.0 INTRODUCTION

1.1 BACKGROUND

Regardless of the extent of waste treatment there will always be slightly contaminated end products that cannot be processed further. These materials must be either disposed in a manner that provides long term safety to human health and the environment, or stored until new techniques are developed to process them.

As part of the Ontario Waste Management Corporation (OWMC) Phase 3 studies Gartner Lee Associates Limited was retained to undertake the first stage of an evaluation of alternative disposal options. Stage 1 evaluates the alternatives from a hydrogeologic and geologic perspective only with some consideration of preliminary regulatory and preliminary geotechnical aspects.

Although the OWMC Facilities Development Process is exempt from the Ontario Environment Act (1975) the basic philosophies embodied in this Act have been guiding OWMC's approach to approval. An evaluation of alternative means of disposal is a requirement under the Environmental Assessment Act. (1)

Disposal options that are identified as potentially viable in Stage 1 are recommended for further, more detailed investigation under Stage 2. Although the scope of the Stage 2 studies has not yet been determined, we anticipate it will compare these alternatives from perspectives such as: engineering feasibility, social impact, transportation, biological impact, economics and atmospheric dispersion considerations.

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(1) In July, 1985 the OWMC Facilities Development Process was brought under the terms and requirements of the Ontario Environment Act (1975), and will be presented to the Environmental Assessment Board in public Hearings, for approval.

1.2 SCOPE AND OBJECTIVES

The objective of this study is to complete an evaluation of possible waste disposal options, based on hydrogeologic, geologic, preliminary regulatory and preliminary geotechnical considerations only. The evaluation discusses the advantages and disadvantages of each disposal option and based on these factors makes recommendations on which options should be considered for further evaluation in Stage 2. The study is qualitative, being completed through a review of available literature and file data only. No site visits, field investigations, or evaluations through computer modelling were undertaken.

The disposal options studied were:

(1) Deep well disposal,
(2) Land treatment,
(3) Active Conventional Engineered Landfill,
(4) Active Above ground Engineered Landfill,
(5) Passive Deep Entombed Engineered Landfill,
(6) Passive Shallow Entombed Engineered Landfill,
(7) Disposal in existing mines in Precambrian igneous and metamorphic rocks, and
(8) Disposal in existing mines in Paleozoic sedimentary rocks.

Consideration was also given to co-disposal at municipal landfills.

1.3 FORMAT

This report has been divided into the following major sections:

1.0 Introduction
2.0 Deep well disposal
3.0 Landfills
4.0 Land Treatment
5.0 Mine Disposal

1.4 METHODOLOGY

This evaluation was based only on a review of the literature, and, where available, unpublished data. No field investigations, laboratory experiments, computer modelling or site visits were undertaken.

Due to the multitude of on-going research and available information in the U.S.A., the American ground water consulting firm of Geraghty and Miller, Inc. was retained to provide a state-of-the-art review of the disposal options as they are presently being used and/or researched in the U.S.A. The Geraghty and Miller, Inc. report is bound in a separate document as Volume 2.

Information was accessed through a number of sources including:

(1) the library and files of Gartner Lee Associates Limited,
(2) the library and files of Geraghty and Miller, Inc.,
(3) computerized search of scientific literature data bases,
(4) published computerized literature searches,
(5) meetings and telephone conversations with regulatory agencies, and

(6) telephone interviews with experts in various technical disciplines.

A number of personal contacts were made with regulatory agencies and waste disposal experts by both Gartner Lee Associates Limited and Geraghty and Miller, Inc. In Ontario, government personnel were contacted from the Ministry of the Environment, the Ministry of Natural Resources, and the Ministry of Labour. The Federal Departments of Environment and Energy, Mines and Resources, and several provincial environmental ministries other than Ontario were also contacted. These contacts were made to solicit expert opinions, obtain unpublished data and confirm regulatory considerations. All contacts were approved by OWMC.

On-going with the collection of publications and data was the development and approval by OWMC of the study assumptions and specific descriptions for the disposal options.

The information collected was used to determine the hydrogeologic, geologic, geotechnical and regulatory advantages and disadvantages of each disposal option from a generic viewpoint. The importance of these advantages and disadvantages were then qualitatively assessed to determine which disposal options had the greatest potential as disposal alternatives for OWMC's wastes or treated waste residues and therefore should be considered for further evaluation in Stage 2. The reasons for recommending a particular disposal option for further evaluation or not are explained qualitatively in the individual sections on each disposal alternative.

1.5 STATEMENT OF ASSUMPTIONS

To adequately set a base upon which an evaluation can be made, a series of assumptions had to be developed early in the study. These include some general assumptions as well as specific assumptions for individual options. All assumptions were discussed and approved by OWMC. They are outlined below:

1.5.1 GENERAL ASSUMPTIONS

(1) From a hydrogeologic perspective, the primary objectives of an acceptable disposal option are:

(a) to protect ground and surface water resources, and
(b) to protect human health

(2) The waste characteristics will be as outlined in Section 1.6.

(3) The disposal options will be assessed for southern Ontario only (i.e. south of the 46th parallel).

The reason for this last assumption is mainly due to transportation concerns and centres of waste generation as established in Phase 1 and 2 of OWMC's overall Waste Facilities Development Process (Ontario Waste Management Corporation 1982, 1983).

1.5.2 ASSUMPTIONS SPECIFIC TO DEEP WELL DISPOSAL

(1) Deep well disposal will be assessed for treated and untreated liquids only.

The physical processes governing disposal in a well require the wastes to be in liquid form.

(2) Only deep well disposal in Cambrian formations will be considered.

A preliminary study (Gartner Lee Associates Limited. 1982, p41) identified the Cambrian formation to have the best potential for deep well disposal in Ontario.

1.5.3 ASSUMPTIONS SPECIFIC TO LAND TREATMENT

(1) Irrigation will be assessed for treated liquids only.

The physical processes governing irrigation require that the wastes be in liquid form only. Considering the potentially dangerous and volatile nature of the untreated liquids, disposing of these in liquid form directly onto the ground could lead to a direct health concern through air transport of pollutants and therefore has been assumed to be unacceptable.

(2) Landfarming will be assessed for treated and untreated sludges only.

The process of landfarming requires the waste to be in sludge form. If the waste is liquid, irrigation is occurring.

1.5.4 ASSUMPTIONS SPECIFIC TO LANDFILLING

(1) The Landfill designs are to be assessed for treated solids and sludges only.

OWMC has "adopted the principle that nothing hazardous will be deposited in its landfill facilities that has not been treated previously" (Ontario Waste Management Corporation 1982, p 28).

(2) Leachate characteristics are as outlined in Section 1.6.4.

(3) Regardless of the design, all landfills will be located in the same hydrogeologic environment; i.e. a thick, fine grained deposit of low permeability.

These deposits are expected to provide the best capabilities for natural protection of the environment. The rationale for this assumption is discussed in more detail in Section 3.3.

1.5.5 ASSUMPTIONS SPECIFIC TO MINE DISPOSAL

(1) Only existing mines are considered as potential waste repositories.

(2) This option will be evaluated for natural containment only.

Due to the depth and inaccessibility of mines for future maintenance the underlying philosophy for mine disposal is to place minimal reliance on engineering and rely on the natural environment for containment of contaminants.

(3) Both treated and untreated wastes in either fluid or solid phase will be considered.

Treated and untreated waste characteristics are as discussed in Section 1.6.

(4) The annual volume to be disposed is in the range of 150,000 to 420,000 cubic m/a.

These volumes assume disposal of all solids and liquids. The range is for no solidification at a 150,000 t/a facility to total solidification at a 300,000 t/a facility. A conservative density of 1,000 kg/m^3 was used to provide volume estimates for no solidification. For total solidification the maximum volume stated in a memo to OWMC by M.M. Dillon (1983) was prorated for a 300,000 t/a facility.

(5) No aggregate quarries or pits are considered in this study.

Aggregate quarries or pits are omitted from consideration based on hydrogeologic factors. Aggregates are mainly sand and gravel deposits or bedded limestone, both of which are highly permeable. These cannot be relied on for natural containment of contaminants.

(6) Mining and disposal operations may be concurrent.

If sufficient underground space is available within a given mine, then continuing mining operations should not preclude utilizing space for disposal operations.

(7) Solution cavity mining of salt beds are not considered as mines for the purposes of this study.

The dimensions of solution cavities are not always fully known and therefore may potentially intersect rocks of higher permeability.

1.6 WASTE CHARACTERISTICS

In an evaluation of various disposal options we must consider the characteristics and quantities of wastes being disposed since the practicality of some disposal alternatives is highly dependent on these factors. For example, in deep well disposal knowledge of the waste liquid chemistry and quantity is required to determine waste/formation water compatibility and injection capacities.

1.6.1 TREATED SOLIDS

The majority of solid residues produced as by-products of the treatment process will be inorganic and relatively inert in nature. However, some contaminants will be present. A discussion of waste treatment residues by Hrudey (1983a), for example, indicates the major contaminants are expected to be heavy metals. Also present will be significant levels of other inorganic elements such as Al, Ca, Cl, F, Mg, Na, K, major nutrients such as NO_3 and PO_4, and sulphate (SO_4). Low, residual concentrations of toxic organics will also likely be present.

OWMC has not yet decided whether the solid residues will be mixed with a solidification agent. Solidification will not remove the contaminants but it will disperse and fix them throughout the matrix. Provided the solidification process has been chosen based on treated waste residue characteristics, solidification should reduce (but not totally prevent) the leachability of most contaminants (Colussi and Mullen 1984, U.S. Environmental Protection Agency 1982 and 1983).

For the purposes of this evaluation it will be assumed that the treated waste residues are not solidified. A discussion of the advantages and disadvantages of solidification is beyond the scope of this report.

TABLE 1: CHEMICAL CHARACTERISTICS OF LIQUID EFFLUENT FROM THE EBENHAUSEN PHYSICAL/CHEMICAL TREATMENT PLANT

PARAMETER	EBENHAUSEN PHYSICAL/ CHEMICAL TREATMENT EFFLUENT (mg/L)
CADMIUM	0.2
CHROMIUM (hexavalent)	<.1
COPPER	1.0
IRON	0.6
MERCURY	0.1
NICKEL	1.0
ZINC	0.8
pH	7.8
CHLORIDE	25000
PHOSPHOROUS	1.0
PHOSPHATE	<1.0
AMMONIUM NITROGEN	4.0
HEXANE EXTRACT	<1.0
PHENOL	<0.5
BOD	30
TOC	50

SOURCES: Proctor & Redfern Limited (1982a)

OWMC is considering two scenarios: a facility to accept 150,000 or 300,000 t/a of waste. The quantity of treated wastes is not known exactly at this time because it depends on the amount and types of wastes accepted, as well as the final choice of treatment processes. Volume estimates in a memorandum by M.M. Dillon (1983) indicates that total solidification will probably produce the largest volume. They estimate a volume as high as 690,000 cubic m/a for 500,000 t/a of waste. Prorating this figure to a 300,000 t/a waste stream gives a volume of 420,000 cubic m/a. This would approximate the upper volume limit.

1.6.2 TREATED LIQUIDS

The major contaminants expected to be in the treated liquids from OWMC's physical/chemical treatment process are heavy metals, major nutrients (e.g. NO_3, PO_4), and elements such as Cl, Na, K, Mg and Ca. Table 1 provides actual effluent data from the physical/chemical treatment plant in Ebenhausen, West Germany (Proctor & Redfern Ltd. 1982a, p4-45). Through discussions with OWMC it was decided we would use the example of Ebenhausen as representative of the upper limit of concentrations of inorganic contaminants in the treated liquids. Concentration measurements or estimates of specific organic contaminants except phenols are not available. However, it is anticipated that other organic contaminants will be present, but at low concentrations.

Physical characteristics of the effluent, such as density and viscosity, have not been reported. However, with chloride concentrations possibly as high as 25,000 mg/L, it has been assumed the solution could be as dense and viscous as sea water. Typical sea water densities range from 1010 to 1050 kg/m^3 (Yarwood and Castle, 1972).

The exact quantities of liquid produced will depend on the amount and types of wastes, as well as final treatment choices, and therefore cannot be confirmed at this time. However, approximate liquid quantity estimates are available that range from 106,900 t/a for partial solidification of the 500,000 waste stream (M.M. Dillon, 1983 Table IV) to 320,100 t/a for no solidification of a 500,000 t/a waste stream (Proctor & Redfern Limited, 1982b Fig. 7.3). The lower number does not include aqueous effluent from the incinerator. Neither volume includes leachate output, should a landfill be used and leachate collected. If these numbers are prorated for 150,000 and 300,000 t/a waste streams, treated liquid output could range from 32,070 t/a to 192,060 t/a. Using a conservative density of 1,000 kg/m^3 these represent volumes in the range of 32,070 m^3/a (1.0 L/s) to 192,060 m^3/a (6.1 L/s).

1.6.3 TREATED SLUDGES

If not dewatered some of the treatment process by-products will be sludges. The chemical and physical composition of the sludges have not been investigated, however, they will likely be a mixture of the treated solids and treated liquids discussed above. That is, mainly inorganic in nature, containing heavy metals, inorganic elements such as Al, Ca, Na, Mg, Cl, F, major nutrients such as NO_3 and PO_4, and sulphate (SO_4), with trace levels of organic contaminants. Volume estimates are not available.

1.6.4 LANDFILL LEACHATE

The landfill will be accepting treated solids and sludges only. As outlined previously the contaminants in these treated waste residues are mostly inorganic with only low, residual levels of organic contaminants. It follows, therefore, that contaminants present in the leachate will be mostly inorganic in nature, although trace concentrations of some organics may occur. The exact chemistry of the leachate has not been defined. However, the contaminants are expected to be heavy metals, major nutrients, cyanide, sulphate and anions such as Cl and F.

1.6.5 UNTREATED WASTES

Table 2 summarizes the wide variety in types and quantities of untreated wastes, predicted for acceptance at the OWMC facility (Ontario Waste Management Corporation 1982, Table 2, and M.M. Dillon 1983, Table I). The quantities are approximations only, based on a proration down to 300,000 t/a from estimates by M.M. Dillon (1983) for a 500,000 t/a waste stream.

TABLE 2: QUANTITIES OF UNTREATED WASTES PROJECTED FOR A 300,000 TONNES/YEAR FACILITY

OWMC WASTE CATEGORY	COMMENTS	APPROX. QUANTITY (TONNES/YR.)
01. ORGANIC SLUDGES & STILL BOTTOMS	Mostly sludges	14,087
02. SOLVENTS AND ORGANIC SOLUTIONS	All liquids	4,896
03. OILS AND GREASES	All liquids	7,112
04. OIL/WATER MIXTURES	All liquids	4,212
05. ORGANIC AND OILY RESIDUES	Mostly liquids but some solids & sludges	31,013
06. HEAVY METAL SOLUTIONS AND RESIDUALS	Mostly liquids but some sludges	140,341
07. MISCELLANEOUS CHEMICALS AND PRODUCTS	Mostly solids	11,349
08. PAINT AND ORGANIC RESIDUALS	Sludges and solids	13,950
09. AQUEOUS SOLUTIONS WITH ORGANICS	All liquids	794
10. ANION COMPLEXES	Sludges and liquids	5,519
11. INORGANIC SLUDGES AND RESIDUALS	Sludges and solids	63,858
12. PESTICIDE AND HERBICIDE WASTES	Mostly solids	1,465
14. CLEAN-UP RESIDUALS	Mostly solids	1,404
	TOTAL	300,000

(Based on a proration of quantities in memorandum by M.M. Dillon (1983), Table I, Appendix I).

2.0 DEEP WELL DISPOSAL

2.1 INTRODUCTION

This section of the report deals with the practicality and hydrogeologic significance of the deep well injection option for both treated and untreated wastes into the Cambrian formation of southern Ontario. It should be pointed out that deep well disposal is a partial disposal alternative, i.e. it will only handle the liquid portions of the waste or treatment by-products.

An earlier draft working paper was prepared for OWMC by Gartner Lee Associates Limited (1982) that dealt with deep well injection. This provided OWMC with background information and an overview of the Ontario situation with respect to injection feasibility. One of a series of conclusions drawn at that time was that the Cambrian Formation presented the best environment for such disposal potential because of its depth, isolation and general formation characteristics. This was based upon preliminary data from the files of the Ministry of Natural Resources (MNR), Petroleum Resources Branch. A recommendation at that time was to conduct a more detailed review of these data to provide a clearer picture of the feasibility of Cambrian formation disposal.

The purpose then of this section is to look specifically at the Cambrian Formation in order to provide to OWMC more detailed assessment of its suitability for disposal of either the treated and/or untreated wastes expected at the OWMC facility.

Since the Cambrian Formation parallels Lakes Erie and Huron and the International Border the consulting firm of Geraghty & Miller, Inc. was requested to research the deep well disposal situation in the bordering states of New York, Pennsylvania, Ohio, and Michigan. Illinois was also included. This was felt to be of vital importance because the Cambrian rocks extend from Ontario into these states. However, it should be noted that the Cambrian formations are more deeply buried in these states because of the regional dip of the associated basins. The report of Geraghty & Miller is bound in a separate document for reference as Volume 2. Excerpts have been incorporated into the discussions that follow. In summary, deep well injection in the Cambrian is being used at the present time in the above noted states.

The following evaluation is based on both published and available but unpublished literature research information. Further data was obtained from the files of the Petroleum Resources Branch of the Ontario Ministry of Natural Resources in London in the form of oil and gas well logs, drill stem tests (DSTs) and fluid chemistry lab results for the Cambrian. Gartner Lee staff analyzed the DST's for aquifer characteristics; i.e. permeabilities, static pressures, flows, etc. In addition, data was received from the Ontario Geological Survey for cores recovered from a recent series of test holes by the Survey. Meetings and discussions were held with Ontario government regulatory agencies, i.e. the Ministry of the Environment (MOE) and Ministry of Natural Resources (MNR), relative to the current status of deep well disposal.

2.2 FACTORS AFFECTING DEEP WELL DISPOSAL

The overall requirements for deep well injection in terms of the proper hydrogeologic setting and the characteristics of the waste to be injected were described in detail in the working paper by Gartner Lee Associates Limited (1982). Only the highlights of these aspects will be provided here in order to provide the reader with the necessary background to understand the specifics and analyses that follow. This section will outline the factors and their significance and describe the OWMC proposed waste stream. The properties of the Cambrian geologic formation, in terms of disposal feasibility will be discussed in the next section.

2.2.1 WASTE FACTORS

The liquid waste to be injected must be characterized and assessed from;

(1) the physical characteristics,
(2) the chemical properties, and
(3) the quantity to be disposed.

These aspects are then compared to the capacity, capability and compatability of the receiving formation. The physical characteristics and quantities of the liquid wastes to be disposed are related to the formations' ability to safely handle the volumes and pressures imposed on it. The chemical compatability is associated with the mixing of formation waters with the injected liquids and their effects on permeability and porosity of the receiving formations.

2.2.1.1 Physical characteristics

(1) Density: The natural waters at great depth are saline with densities in the order of 1200 kg/m . If the density of the injected fluid is less it will tend to float on the natural waters whereas more dense waste will sink.

(2) Viscosity: More viscous waste waters will clog porous media (sandstone) when compared to waste fluids that have a viscosity similar to the natural waters.

(3) Temperature: Increases in waste water temperatures may increase corrosion rates and rates of chemical reactions. The corrosion will decrease operational time of the well and the chemical reactions could cause suspended solids to form which could plug the well. This could also affect initial hydraulic gradients.

(4) Suspended Solids: Unfiltered waste waters will contribute to formation "clogging", reducing the permeability.

(5) Gas Content: Similar to suspended solids, entrained gas bubbles can plug pores of an injection reservoir reducing permeability. Dissolved gases will promote corrosion of surface and well equipment, and may react with other chemicals to form "clogging" solids.

2.2.1.2 Chemical characteristics

(1) Dissolved Solids: Through chemical reactions with naturally saline water, various dissolved solids can cause precipitates to form which can "clog" porous media.

(2) pH: Low pH acidic waters will increase the permeability

of carbonate formations or sandstones with carbonate minerals in their matrix. This is the result of the dissolution of calcium and magnesium carbonate. Over long periods this dissolving process may erode the formation in the immediate vicinity of the well outlet which can cause well collapse and in turn well failure.

High pH wastes (alkaline) may cause well corrosion depending on effluent chemistry.

(3) Reactions: Specific waste waters and formation waters should be sampled prior to disposal in order to predict reactivity. Adverse combinations could form precipitates that will "clog" formation pores.

(4) Biological: Pore "clogging" can also develop as a result of algae or bacteria forming in the porous media in the disposal zone, especially where the fluids have been stored in an open pond before injection.

The wastes to be associated with the OWMC facility are described in Section 1.6 of this report. The wastes to be considered for deep well injection are the liquids fraction only in either treated or untreated form.

The untreated wastes anticipated to be received at the OWMC facility are shown on Table 2, Section 1.6. Materials such as sludges and oils and greases will be unsuitable for deep well disposal. These wastes would require significant pretreatment, such as filtration to remove solids and dilution or chemical alteration to reduce the viscosity and potential incompatibility with formation waters. About half of the anticipated volumes of untreated wastes might be considered for injection. However, this will be dependent on waste specific chemistry.

The treated liquid waste volumes have been estimated to vary from 3.2E+07 L/year (1.0 L/s) (13 Igpm) to 1.9E+08 L/year (6.1 L/s) (81 Igpm). The physical and chemical properties cannot be detailed at this point. However, representative effluent chemistry from Ebenhausen (Table 1 in Section 1.6) shows that the resulting effluent from the waste treatment facilities may be a brine with chloride concentrations as high as or exceeding 25,000 ppm. These concentrations are similar to seawater. The specific gravity may be considered similar to seawater (1.01 to 1.05).

2.2.2 HYDROGEOLOGIC FACTORS

In order to safely accept liquids for disposal, an injection zone should exhibit the following hydrogeologic characteristics.

(1) the zone should have sufficient permeability, porosity, thickness and areal extent to act as a liquid storage reservoir at safe injection pressures;

(2) the zone should be vertically below the level of fresh water circulation and be confined by overlying and under lying strata that are impermeable (Warner, 1968);

(3) the zone should have small horizontal gradients so that waste movement is not rapid away from the injection site;

(4) the zone should have no unplugged wells that penetrate the formation in the vicinity of the disposal well and could act as conduits for contaminants to reach overlying aquifers. (McLean, 1968);

(5) the zone should be in an area of seismic stability;

(6) the zone should not have a hydraulic head higher than the ground surface (artesian conditions) so that waste cannot return to the surface in the event of a pump or system failure. Unless confinement at depth can be assured, operating pressures or heads should be below the piezometric heads of the lowermost fresh water aquifers.

(7) the zone should be at sufficient depth and should have adequate thickness of low permeability overlying material to prevent migration of disposal fluids into overlying ground water aquifers.

2.3 FEASIBILITY FOR CAMBRIAN DISPOSAL

2.3.1 INTRODUCTION

The feasibility of the deep well injection process is governed by several factors:

(1) The nature and volume of the wastes to be injected.

(2) The geologic setting, i.e. the presence of a deep suitably permeable and porous formation, that is confined and does not contain a resource. It must be isolated from potable ground water sources and be stable geologically and seismically. Formation pressures should be receptive to injection.

(3) The legal and regulatory considerations, and

(4) The economics, cost/benefit aspects.

Economics and cost/benefits are beyond the scope of this study.

Another factor not noted above is that of public acceptability which is also beyond the scope of the present work. As noted in the history of Ontario deep well disposal operations, past problems have occurred because of technical and operational reasons in the shallow Detroit River Group rocks. Therefore a solid technical and educational program would be mandatory in overcoming many of the concerns that were no doubt established in the 1970s.

The regulatory aspects were presented in our earlier working paper of 1982. It appears that the Cambrian meets the disposal criteria laid out by Van Everdingen and Freeze (1973) and Ontario Regulatory Agencies. However, approval would have to be attained based on site specific and waste specific criteria.

2.3.2 THE CAMBRIAN FORMATION

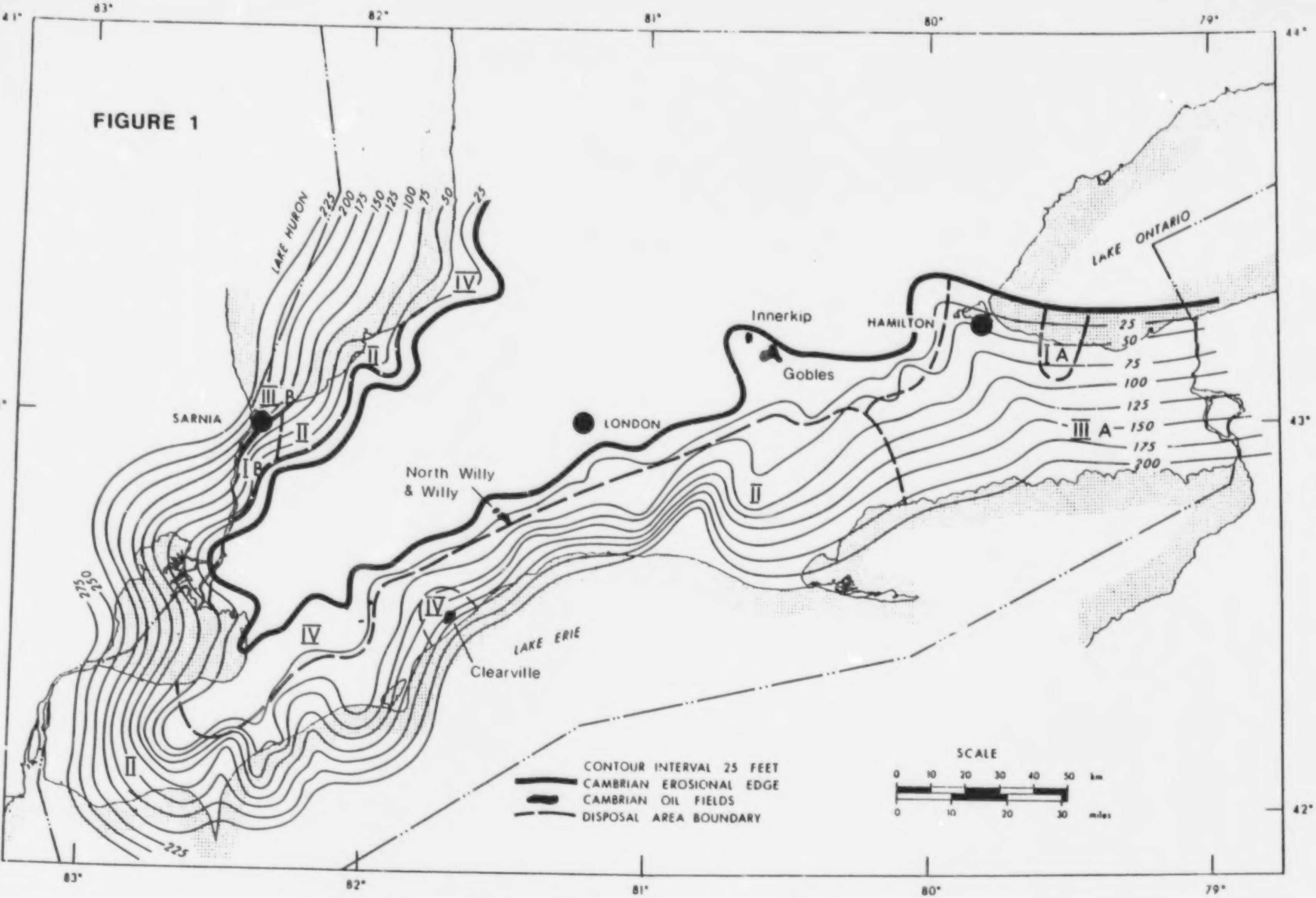
2.3.2.1 Physical and geologic characteristics

The Cambrian Formation is the lower-most sedimentary rock strata in south central and western Ontario. It directly overlies the granitic rocks of the buried Pre-Cambrian of the Canadian Shield as it slopes off to depth. As shown on Figure 1, this bedded rock unit parallels Lake Erie and Huron. This unit feathers out along its northern and eastern boundary, i.e. the erosional edge as shown. Conversely it thickens as one proceeds towards the U.S., into Ohio and Michigan. Figure 1 shows isopach (i.e. formation thickness) contours. The estimated formation thickness in the Niagara Penninsula is up to 60 m (200 ft) and the zone in south-western Ontario near Sarnia is slightly thicker (80 m). This sedimentary bedrock formation forms the lowermost part of two basin structures, the Michigan Basin to the west and the

Appalachian Basin to the south. A broad high ridge in the Pre-Cambrian surface is termed the Algonquin Arch and separates these basins. These cambrian sediments are not located on top of the arch so that their lateral geographic extent in southern Ontario is limited as shown. As well as becoming thicker as one proceeds towards the U.S., the unit becomes more deeply buried. In the Niagara Penninsula the top of the Cambrian is found at 600 to 900 m below ground surface while in the Sarnia area it occurs at about 1400 m depth. The elevation of the top of the Cambrian Formation is shown in Figure 2. Cross-section AB on Figure 3 shows the north to south relationship from Toronto through Lake Ontario to Lake Erie. The Cambrian is thus buried beneath deep sequences of Paleozoic limestones and shales and is sealed at depth far below the potable water well aquifers. This is part of the rationale for its consideration. Near the centre of these basins the Cambrian is buried at 4300 m in Michigan and at 10,700 m in the Appalachians. There is good lateral continuity in the unit especially in its physical characteristics, however, there is considerable variation vertically within the unit in the basins. Because this rock unit directly overlies the granitic Precambrian, that surface controls a number of the structural features and these have been mapped by Turek and Robinson (1984). Note that a series of faults have been identified in the Windsor-Chatham area as shown on Figure 4. Some have vertical displacements of as much as 100 m. These are not active faults. The Pre-cambrian bedrock and overlying rocks have been stable tectonically over a long period of geologic time.

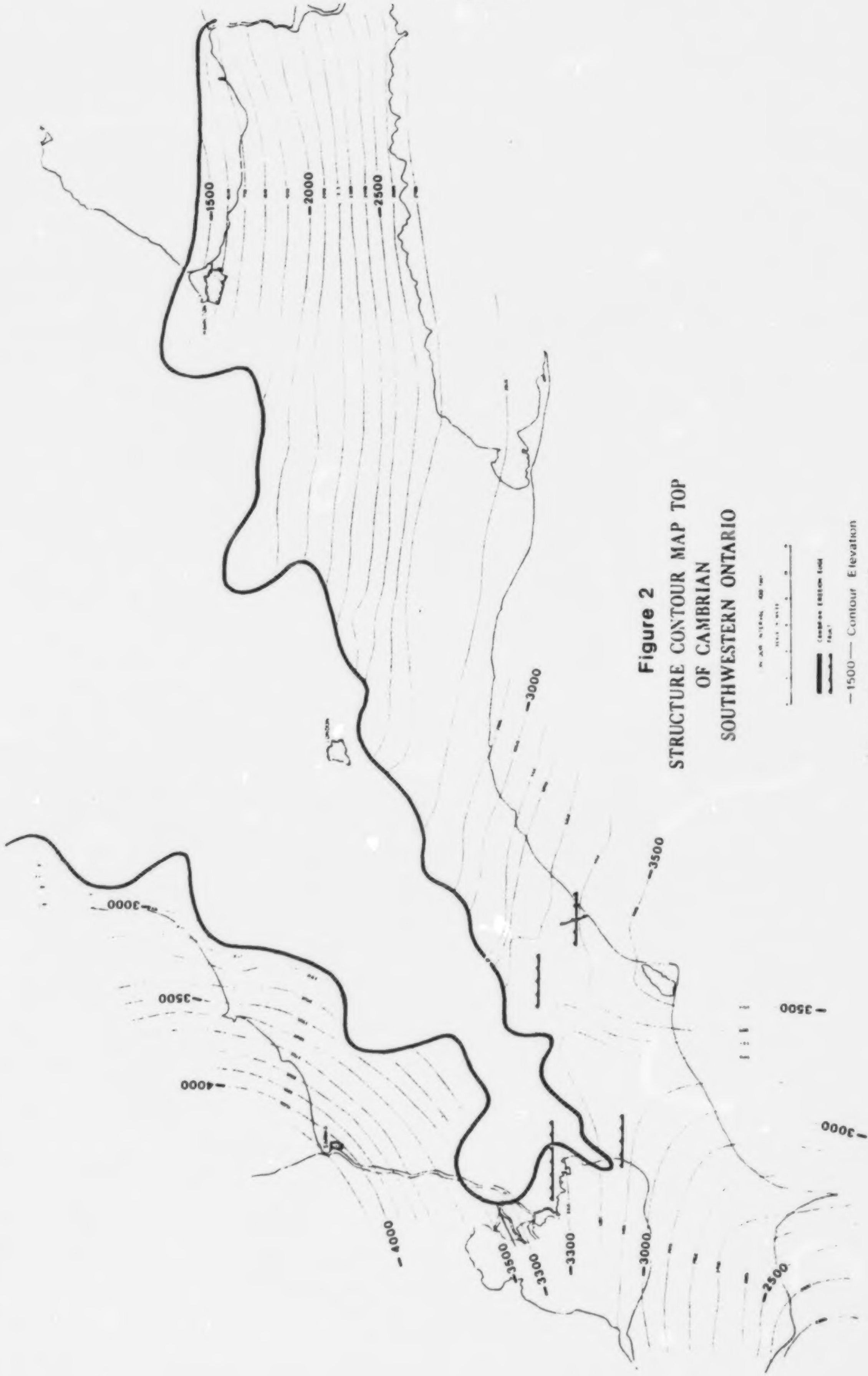
Another zone of Cambrian rocks occurs in Eastern Ontario. Due to its shallow nature (it outcrops along the shield), it has not been considered further for disposal.

FIGURE 1


83°
82°
81°
80°
79°
41°
44°
43°
42°
LAKE HURON
LAKE ONTARIO
LAKE ERIE
SARNIA
LONDON
HAMILTON
Innerkip
Gobles
North Willy
& Willy
Clearville
I A
I B
II
III A
III B
IV
25
50
75
100
125
150
175
200
225
250
275
CONTOUR INTERVAL 25 FEET
CAMBRIAN EROSIONAL EDGE
CAMBRIAN OIL FIELDS
DISPOSAL AREA BOUNDARY
SCALE
0
10
20
30
40
50
km
0
10
20
30
miles

Isopach map of total Cambrian in southwestern Ontario, with indication of disposal potential (after McLean, 1968)

(modified from Van Everdingen, 1974)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-2000
-2500
-3000
-3500
-3000
-3500
-4000
-3500
-3000
-4000
-3500
-3300
-3300
-3000
-2500

Figure 2
STRUCTURE CONTOUR MAP TOP
OF CAMBRIAN
SOUTHWESTERN ONTARIO

—1500— Contour Elevation

(from McLean 1968)

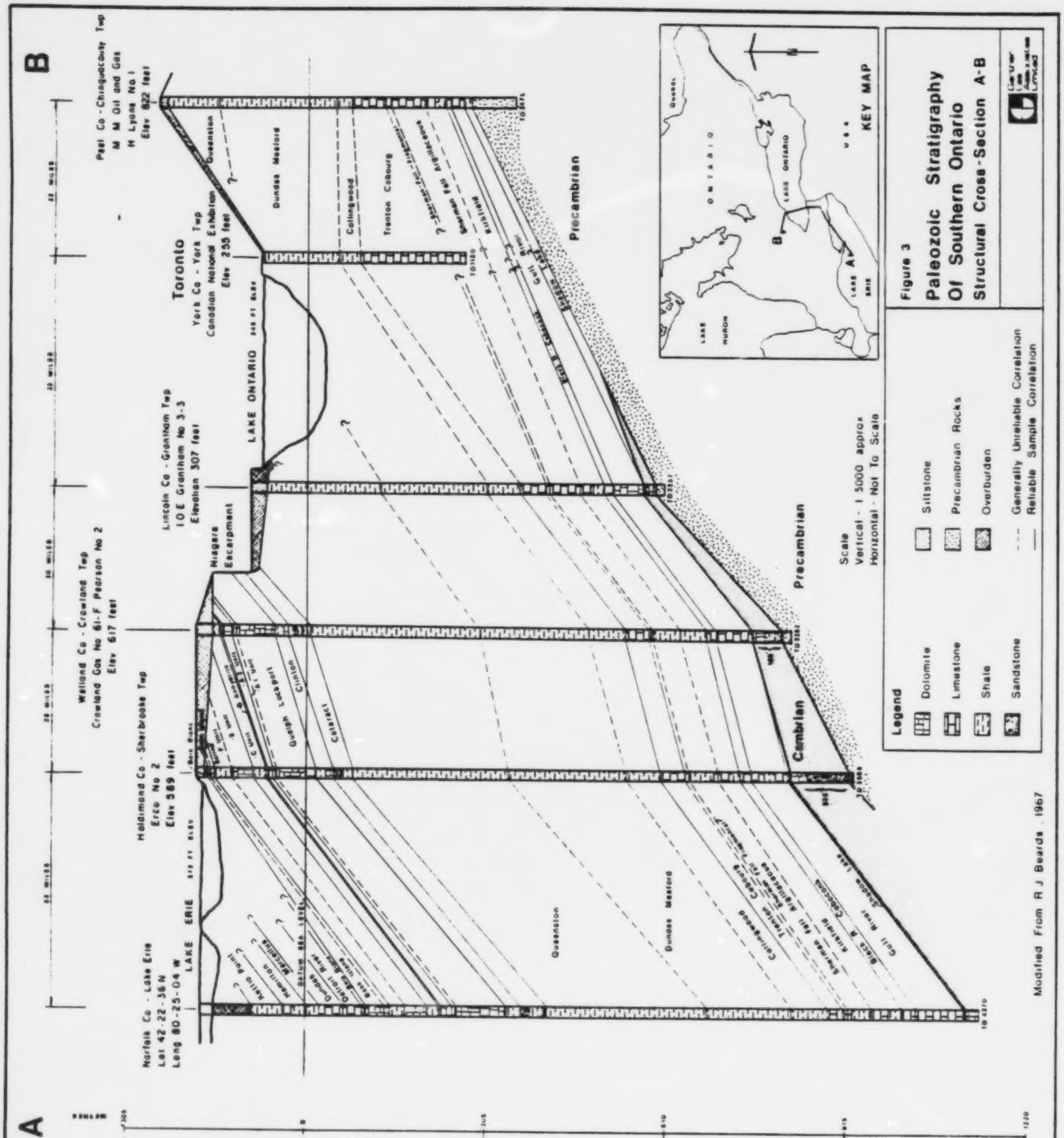
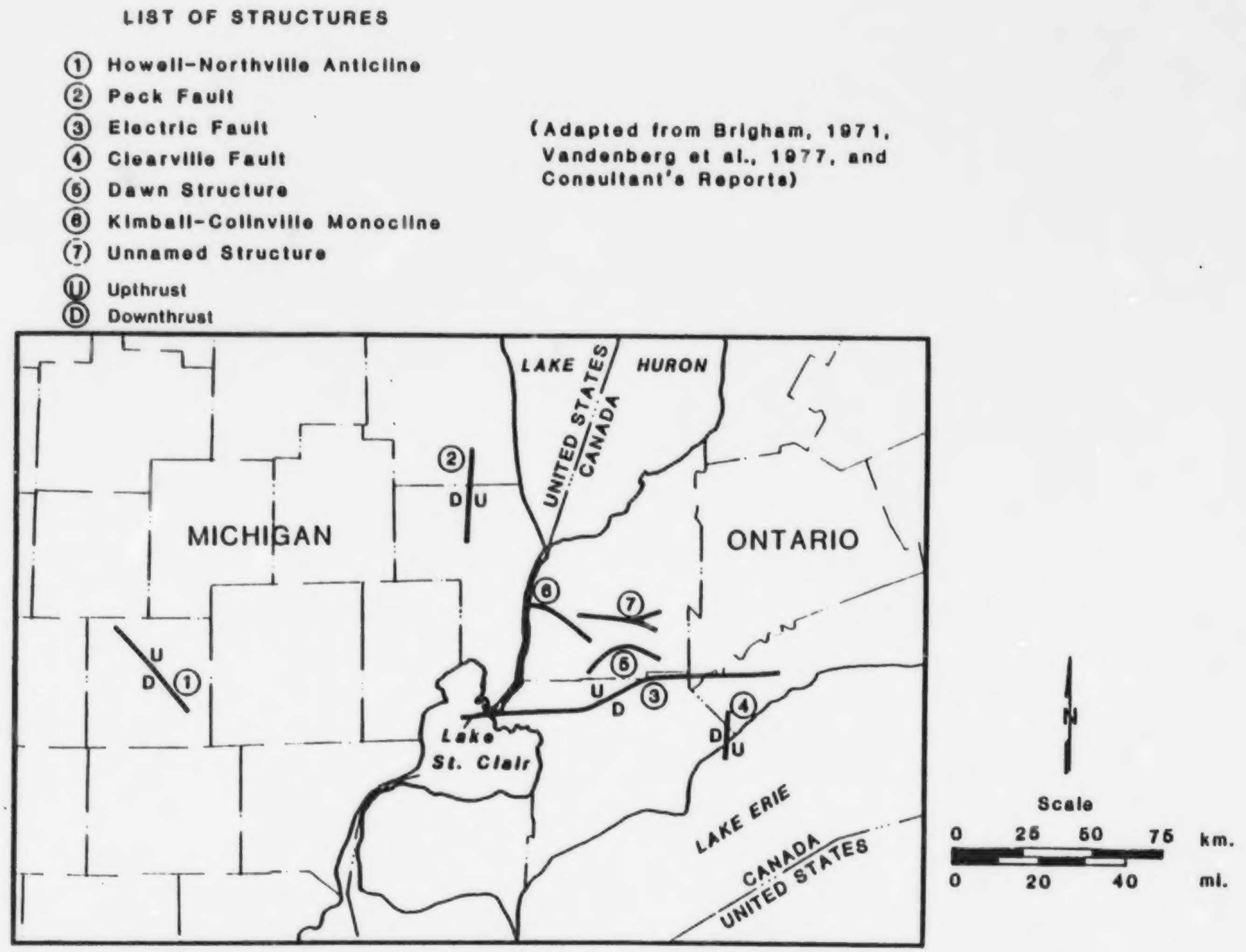

A
B
ELEVATION
FEET
METRES
0
1000
2000
3000
4000
Norfolk Co - Lake Erie
Lat 42-22-36 N
Long 80-25-04 W
Haldimand Co - Sherbrooke Twp
Erie No 2
Elev 589 feet
Welland Co - Crowland Twp
Crowland Gas No 61-F Pearson No 2
Elev 617 feet
Lincoln Co - Grantham Twp
10 E Grantham No 3-3
Elevation 307 feet
Toronto
York Co - York Twp
Canadian National Exhibition
Elev 235 feet
Peel Co - Chinguacousy Twp
M M Oil and Gas
H Lyons No 1
Elev 822 feet
LAKE ERIE
LAKE ONTARIO
Niagara Escarpment
Kettle Point
Hamilton
Marcellus
Dundas
Detroit River
Bois Blanc
Bass Islands
Guelph Lockport
Clinton
Cataract
Queenston
Dundas Meaford
Collingwood
Trenton Cobourg
Sherman Fall Argillaceous
Kirkfield
Coboconk
Black River
Gull River
Shadow Lake
Cambrian
Precambrian
Scale
Vertical - 1 5000 approx
Horizontal - Not To Scale
Legend
Dolomite
Limestone
Shale
Sandstone
Siltstone
Precambrian Rocks
Overburden
Generally Unreliable Correlation
Reliable Sample Correlation
KEY MAP
ONTARIO
LAKE HURON
LAKE ONTARIO
LAKE ERIE
Quebec
U.S.A.
Modified From R J Beards , 1967

Figure 3

Paleozoic Stratigraphy Of Southern Ontario Structural Cross-Section A-B


LIST OF STRUCTURES
① Howell-Northville Anticline
② Peck Fault
③ Electric Fault
④ Clearville Fault
⑤ Dawn Structure
⑥ Kimball-Colinville Monocline
⑦ Unnamed Structure
Ⓤ Upthrust
Ⓓ Downthrust
LAKE HURON
UNITED STATES
CANADA
MICHIGAN
ONTARIO
Lake St. Clair
LAKE ERIE
CANADA
UNITED STATES
U
D
N
Scale
0 25 50 75 km.
0 20 40 mi.

(Adapted from Brigham, 1971, Vandenberg et al., 1977, and Consultant's Reports)

Figure 4. Index Map of Geologic Structures, Southwestern Ontario and Eastern Michigan

(from Underground Resource Management Inc. 1984)

The lithology, texture and stratigraphic relationships of the Cambrian have been described by a number of authors. In summary, the rock is a cemented quartzitic sandstone and conglomerate. Variations described in the literature show the material to change from a fine to coarse, clean quartz sand to more dense dolomitic sandstones and lower permeability sandy dolomites. Porosities of the medium are reported in the range of 1 to 20%, typical of sandstones. It would appear that texture changes laterally and vertically. Where more permeable, sandier fractions grade into the tighter dolomites. These create structural traps and hydraulic boundary conditions for fluids, especially oil and gas.

2.3.2.2 Hydrogeologic characteristics

A review of oil and gas well records from the Ministry of Natural Resources files in London showed that the total number of deep wells completed into the Cambrian in Southern Ontario is in the order of a few hundred wells. However, the amount of specific hydrogeologic data available for actual analysis from the Cambrian is very limited. Most had no hydrogeologic testing but rather they had only rock lithology determined. Selected well records containing hydrogeologic information, i.e. drill stem tests, were reviewed and analysed in an attempt to determine the permeability and static head characteristics of the Cambrian formation.

Well record data indicate variations in measured static head to be considerable within the same counties and often within the same township. Static levels varied from about 15 m from surface to greater than 1000 m. It is uncertain whether these values represent considerable variations in the hydrogeologic conditions of the Cambrian within short distances or whether there were inherent biases in the data obtained. For example, allowing insufficient time for the water level to respond to static would give apparent static levels lower than the true values.

Several drill stem tests were available from the Cambrian in wells completed in Lake Erie and the southern part of Oxford County. Analysis of these tests showed hydraulic conductivities of 1E-08 to 1E-09 m/s, with one test result as low as 1E-11 m/s. These results compared favourably with laboratory permeabilities conducted on core samples taken from the Cambrian in Elgin County, Dunwich Township which ranged between 1E-07 and 1E-09 m/s. A recent laboratory core analysis on the Cambrian of a deep well drilled by the Ontario Geological Survey in Elgin County, Yarmouth Township showed a range of laboratory hydraulic conductivities from nondetectable to 1E-05 m/s. The majority of the core showed relatively low hydraulic conductivities in the order of 1E-08 m/s with the higher values likely attributable to isolated fractures or irregularities in the core. The limited data suggest that moderately low permeabilities can be expected in the Cambrian, although there may be local variations of more permeable zones.

2.3.2.3 Water chemistry

Chemical analysis of the formation waters from the Cambrian indicates they are brines with chloride contents of 100,000 to 200,000 mg/L and total dissolved solids in excess of 300,000 mg/L. The specific gravity of these brines varies from 1.1 to 1.2 and pH values are generally between 6 and 7. The chemistry data for the Cambrian also shows some variations laterally and horizontally and appears to become slightly less saline at shallower depths.

2.3.2.4 Oil and gas development

Oil and gas has been found to be present in significant numbers of deep exploratory wells and a total of 12 oil and gas pools have been found within the Cambrian of Southern Ontario. A production summary of these, as shown on Table 3, indicates that only 9 of these fields have had commercial production and that only 5 were actively producing as of 1981. The location of some of these active oil and gas fields is shown on Figure 1. It appears that most of these fields have had significant reductions in oil and gas production between 1977 and 1981. Thus the relative contribution of these fields to the total Ontario oil and gas production is declining and represents only a small portion of the total production.

The reservoir trapping mechanism for most Cambrian oil and gas pools is stratigraphic, however there appears to be some structural control related to faulting in the Clearville and Willey fields. Relatively few exploratory holes have been drilled into the Cambrian in comparison to other strata such as the Devonian which has been intensively drilled throughout Southwestern Ontario.

It appears that the Cambrian has been explored for oil, however, it does not appear to be a significant producer of oil and gas in most areas.

2.3.3 WASTE DISPOSAL IN THE CAMBRIAN

2.3.3.1 Overview

The history of deep well disposal of wastes in Southern Ontario has been focused upon formations of the Detroit River Group. A detailed analysis and discussion of deep well disposal in this zone has recently been completed by Underground Resource Management (1984) for the Ontario Ministry of the Environment.

TABLE 3: SUMMARY OF ONTARIO OIL FIELDS IN THE CAMBRIAN

COUNTY	POOL	DISCOVERY DATE	PRODUCING FORMATIONS	RESERVOIR & TRAPPING MECHANISM	DEPTH (METRES)	ACTIVE WELLS		1981 PRODUCTION (Oil m^3 - Gas 10^3m^3)	CUMULATIVE PRODUCTION (1981) (Oil m^3 - Gas 10^3m^3)
						GAS	OIL		
ELGIN	New Glasgow Gas	1959	Cambrian	Porosity pinchout in sandy dolomite	1201	—	—	—	—
	Willey Oil & Gas	1964	Cambrian	Sandy dolomite in fault trap	1079-1102	—	12	5,778.9 O	231,020.5 O
KENT	Clearville Oil	1962	Cambrian	Sandy dolomite in tilted fault block	1188-1206	—	10	3,102.8 O	205,644 O
	Electric Gas	1948	Cambrian	Dolomite in stratigraphic trap	1209-1215	—	—	—	1,869.7 G
	St. Patricks Gas	1970	Cambrian	Dolomite in stratigraphic trap	1132-1134	—	—	—	—
	Zone 5-III Oil	1925	Cambrian	Dolomite in stratigraphic trap	1204-1213	—	—	—	92.0 O
MIDDLESEX	North Willey (formerly Ekfrid) Oil & Gas	1973	Cambrian	Dolomite in stratigraphic trap	1085-1088	—	2	472.9 O	6,747.9 O 1,898.0 G
OXFORD	Gobles Oil & Gas	1959	Cambrian	Dolomitic sandstone in stratigraphic trap	891-907	—	38	2,425.1 O	214,130.2 O 25,353.6 G
	Innerkip Gas & Oil	1961	Cambrian	Dolomitic sandstone in stratigraphic trap	873-890	5	5	108.0 O 6,915.5 G	3,121.1 O 56,660.8 G
	Innerkip East Gas	1968	Cambrian	Dolomitic sandstone in stratigraphic trap	868-879	—	—	—	2,351.2 G
	Verschoyle Oil	1963	Cambrian	Dolomitic sandstone in stratigraphic	1015-1018	—	—	—	208.4 O
WENTWORTH	Rockton (off map) Gas	1960	Cambrian	Sandstone in stratigraphic trap	719	—	—	—	—

Source: Rybansky and Trevail (1983)

Deep well disposal of liquid wastes in the Detroit River Group has not been successful in Ontario due to its shallow depth and lack of hydraulic isolation and predictability. Disposal of wastes are now limited to brines.

The Cambrian has not been used extensively for waste disposal in southern Ontario. One well in Kent County, near the Lake Erie shore, was shown by McLean (1968) as a disposal well for oil field brine. It appears that a storage well was drilled into the Cambrian in 1965 for Imperial Oil near Sarnia. The history of this well is not known. The drilling of two disposal wells into the Cambrian in 1971 was noted by Van Everdingen (1974). One was located near Sarnia and one in Essex County. No details of these wells were given. There is currently no waste disposal occurring into the Cambrian in southern Ontario.

A proposal to utilize the Cambrian for waste disposal was suggested by Tricil several years ago for Lots 48 and 49 of Moore Township, Lambton County (Ontario Ministry of the Environment, personal communication). This proposal was not followed through. More recently, in late 1976, Cambrian Disposal Limited proposed to utilize an existing well completed into the Cambrian in Canborough Township of Haldimand County for waste disposal. This proposal met with vigorous public opposition and did not proceed further.

Cambrian Formations have been used successfully in the United States for a variety of wastes. A summary of Cambrian injection wells completed in states adjoining southern Ontario has been compiled by Geraghty and Miller, Inc. and is shown on Table 4. Injection has been to depths that are comparable to the Cambrian in southwestern Ontario, however, in most cases the formation

TABLE 4: Selected Data on Disposal Wells Tapping the Mount Simon Sandstone or Its Equivalent.

Site/Company	County	Well No.	Depth (meters)	Interval (meters)	Thickness (meters)	Rate (liters per minute)	Pressure (kilo-pascals)	Porosity (percent)	Permea-bilities cm/sec x 10^{-6}	Waste
NEW YORK										
1. Hooker Chemical		Buffalo, N.Y.2	934	863 - 887	24	545	10,342	--	--	30% HCl
2. Bethlehem Steel		Buffalo, N.Y.3	1,314	1,158 - 1,319	161	95	6,205	--	--	Pickle liquor
INDIANA										
3. FMC Corp.	Vermillion		1,880	1,603 - 1,877	274	189	6,895	6	5.8- 7.7	Brine-200,000
4. Bethlehem Steel	Porter	S28 T37N R6W	1,299	773 - 1,299	526	473	4,827	9	--	Brine, H_2SO_4
5. Bethlehem Steel	Porter	S30 T37N R6W	1,202	765- 1,202	437	473	4,827	10-20	19.8-97	NH_4, phenols, cyanide
6. Bethlehem Steel	Porter	S29 T37N R6W	1,311	771 - 1,303	532	121	103	10-20	19 -97	NH_4, phenols, cyanide
7. Midwest Steel	Porter	S25 T37N R6W	1,313	658 - 1,298	640	1,041	0-207	18	38 -48	HCl
8. Indiana General	Porter	S16 T35N R5W	1,386	858 - 1,389	531	--	345	--	--	NH_4Cl
ILLINOIS										
9. U.S. Steel	Lake	S29 T37N R8W	1,311	738 - 1,302	564	795	1,379	14.3	412	Pickle liquor
10. Inland Steel	Lake	S14 T37N R9W	1,325	719 - 1,323	604	208	0-1,586	12	305	Pickle liquor
MICHIGAN										
11. Chemtron	Ottawa	S30 T5N R14W	1,801	--		132	1,551-1,724	--	--	H_2SO_4, HCl, NH_4
12. Chemtron	Ottawa	S30 T5N R14W	1,797	1,404 - 1,797	393	132	1,551-1,724	--	--	Pickle liquor

(from report by Geraghty and Miller, Inc., see Volume 2)

TABLE 4: (continued)

Site/Company	County	Well No.	Depth (meters)	Interval (meters)	Thickness (meters)	Rate (liters per minute)	Pressure (kilo-pascals)	Porosity (percent)	Permea-bilities cm/sec x 10^{-6}	Waste
OHIO										
13. Empire Reeves Steel	Richland	Section 16, Madison Twp.	1,543	1,518 - 1,543	25	57	2,069	10	8.7	38 million liters disposed
14. Armco Steel	Butler	Section 8, Lemon Twp.	1,005	900 - 986	86	337	2,965	10	241	92.7 million liters disposed
15. Armco Steel	Butler	Section 8, Lemon Twp.	1,001	896 - 985	89	254	552 -	10	241	129 million liters disposed
16. Vistron	Allen	Section 2, Shawnee Twp.	955	847 - 955	108	458	5,392	14	--	1,177 million liters
17. U.S.S. Chemical	Scioto	Green Twp.	1,712	1,681 - 1,696	15	216	9,653	12	26	500 million liters
18. Vistron	Allen	Section 11, Shawnee Twp.	967	853 - 958	105	757	4,978	14	--	1,173 million liters
19. Callio Chemicals	Lake	Perry Twp.	1,851	1,807 - 1,847	40	--	--	--	--	--
20. Vistron	Allen	Section 2, Shawnee Twp.	965	847 - 955	108	723	3,744	14	--	68 million liters

(from report by Geraghty and Miller, Inc., see Volume 2) thickness is much greater than that available in southwestern Ontario. The hydraulic conductivities of the formations are in the range of 1E-06 to 1E-08 m/s, which are similar to slightly better than those found in southern Ontario. Injection rates in about 50% of the U.S.A. wells are noted as being >100 gpm, and on the basis of the volumes injected, many of the wells have operated for a significant time period. It also appears that a variety of injection pressures have been used. Some of the wells have likely developed secondary porosities and permeabilities by hydrofracturing in response to high injection pressures. Acidizing of the well may also have resulted in increased porosities and permeabilities. As a result of thicker formations, hydrofracturing and acidizing, the U.S.A. wells show much better performance than could be expected in Ontario, despite similar measured hydraulic conductivities and porosities.

2.3.3.2 Interaction of the wastes and formation waters

As noted previously, the untreated wastes anticipated at the OWMC facility show a fairly wide variety of characteristics both physically and chemically. Some of these wastes, such as the sludges and oils and greases, will be unsuitable because of the clogging potential in the formation. It appears that the fluids with potential for well disposal represent about one half of the liquid volume total. However, the acceptability of these wastes is highly dependent on specific chemistry. Surface filtering would be required at the minimum before injection of any fluids to remove suspended solids. Bacteria and algae must also be treated.

The untreated liquid wastes are assumed to have greater variability than a treated effluent. Consequently, the prediction of compatability becomes more difficult, especially in the long term with variation of pH, viscosity and overall chemistry. This would complicate operating procedures and monitoring of pressures etc. with time. The danger would also exist for chemical reaction/precipitation in the formation.

The treated wastes as per the example of the Ebenhausen facility, could be in the form of a brine with chloride concentrations as high as 25,000 ppm. This is similar to seawater with a specific gravity of about 1.01 to 1.05.

The formation waters are variable both laterally and vertically. The data base is limited. However, some generalizations can be drawn from the previous section.

pH : 6 to 7
Cl : 200,000 ppm
TDS: 300,000 ppm
spG: 1.1 to 1.2

The formation waters are a non-potable brine, typical of a sluggish flow system with low gradients. A general review of the waste and formation water chemistry do not present any obvious concerns for compatability for the treated fluids. The exception to this may be the specific gravity ratios which will in turn affect the injection head/formation pressure ratio that will be needed to displace the more dense brine if encountered in the rock.

2.3.3.3 Feasibility of injection volumes

The volumes to be injected need to be assessed using several factors relative to the formation;

(1) the permeability,
(2) the porosity available (pore space),
(3) the static or formation pressure head,
(4) the formation thickness,
(5) the formation fluid, and
(6) depth to the freshwater (aquifer) interface, and static heads in that formation.

As described in section 2.3.2.2, the hydraulic conductivities for the Cambrian rocks of southern Ontario appear to be in the range of 1E-08 m/s (10 millidarcies) for the drill stem tests analysed by GLAL staff. This is a low permeability medium.

Values of 15 to 100 millidarcies are commonly reported however, the data base is sparse. Similar values are reported by Geraghty & Miller, Inc. for the Cambrian deposits in the bordering states, down dip. From our review of the laboratory hydraulic conductivity test results, it appears most of the values are in close agreement to the large scale in-situ pump tests. On this basis one can assume that hydraulic conductivity is primary, that is it depends on the pore spaces rather than on fracture or bed openings.

The geographical distribution of the Cambrian rocks was described earlier. The thickness of the unit in southern Ontario increases towards the Lakes to a maximum of about 80 m (260 feet).

These two factors when considered together are directly proportional to the quantity of fluid able to be withdrawn or injected. (Transmissivity = hydraulic conductivity x thickness). This probably explains why the deep wells in Ohio, for example, are able to inject quantities up to rates of 200 gpm. The formation thicknesses there are reported in excess of 200 m. The porosities of about 1 to 20% are common to both areas. One other difference may be the fact that the matrix cement binding the sandstone is occasionally calcareous in Ohio and predominantly siliceous in southwestern Ontario. Therefore acidizing may have greatly enhanced the permeabilities in the U.S. with continued operation, whereas this would not be the case in Ontario.

On the basis of our analysis injecting the smallest volumes of waste, in the range of 1.0 l/s (13 Igpm) seems to be achievable. Values of 6.1 l/s (81 Igpm), which represents the higher range of anticipated waste volumes, appears to be an impractical target. On the other hand, Ontario well fields such as the Gobles Field (see Figure 1) indicate that isolated pockets of higher permeability do exist. In this regard, the publication of McLean (1971) showed fairly distinct target zones for disposal well consideration. However, on the basis of our understanding and personal communications with McLean, the data base used was sparse and the identification of targets as such may not be practical. It is difficult to predict where such areas exists on the basis of existing information. As noted in our earlier report, one cannot assess the well potential until actual testing is done. Therefore, for lower injection quantities, the possibilities for success seem good. However, the higher injection rates may be extremely difficult to achieve and are certainly impossible to predict on the basis of existing data.

Injection pressures and head may also have to be limited to a level lower than the deepest fresh water aquifer. The safe limit to prevent hydrofracturing of overlying beds must also be considered.

2.3.3.4 Contaminant migration

If we assume; (1) the Cambrian formation to be homogeneous and isotropic, and (2) the waste density to be similar to formation thickness, then contaminants will move in all directions from the well as a cylinder. One can carry out an approximate calculation to estimate the extent of formation that is filled or used up by the waste injection. For example, if we use the lower injection rate of 1.0 L/sec (13 Igpm) and assume an aquifer thickness of 15 m with a porosity of 20% the waste cylinder would have a radius of 290 m after a period of 25 years. Injection at the higher rate of 6.1 L/sec (81 Igpm) would result in a waste cylinder with a radius of almost 0.75 km after 25 years.

In reality contaminants will not move in this way. Dispersion will tend to spread the front of contaminants out further than these "plug" flow calculations would indicate. Porosities lower than the 20% will also result in an expanded radius of injected water. Density differences may cause the wastes to migrate in a thin zone at the top of the unit. If inhomogeneities or discontinuities exist, which is the most likely case, the spreading waste mass will not be cylindrical but will be distorted in the direction of highest permeability. In this case even the lower injection volume could result in contaminants migrating long distances from the well. Fracture flow, as opposed to porous media flow, could also result in rapid transport over potentially large distances.

It should also be remembered that the injection pressure cone will extend beyond the contaminant zone noted above. Furthermore, one has to consider pressures rather than hydraulic heads because of density differences between brines and fresh water.

For the above reasons it is difficult to predict the movement of contaminants from the injection well. Due to the depth of the formation and lack of existing data, obtaining the information necessary for prediction becomes difficult. The depth and potential variability in flow paths also makes monitoring difficult and expensive.

The major concern of deep well disposal in the Cambrian is not contamination of ground water in this unit, because this water is naturally a non-potable brine. Instead the concern is that contaminated ground water will migrate into overlying potable aquifers. From our review of the geology, the Cambrian appears to be well isolated from these aquifers. Since very little drilling has been completed into the Cambrian there is minimal potential for old unsealed wells to act as man-made conduits. However, the lack of data on the geologic and hydrogeologic characteristics of the Cambrian formations provides some uncertainty about the natural fate of contaminants injected into this zone. For example, faults have been observed in the Cambrian. If the injection well was installed near a previously unmapped fault zone, it is possible contaminants could migrate up this zone into overlying aquifers, especially if the waste is injected under pressure. Consequently, development of an extensive geologic and hydrogeologic testing program is required. This must be followed up with a detailed monitoring program.

2.3.3.5 Other considerations

One other aspect to consider is the effect deep well disposal may have on oil and/or gas resources. Petroleum fields do exist in the Cambrian. However, since very little exploration has been done at depth the presence or absence of significant wide spread oil and/or gas resources in the Cambrian has not been established at this time. Traps for petroleum seem to be texturally controlled, i.e. in coarser materials up dip near the origin of original sedimentation. These coarser materials may also become potential disposal target zones due to their higher permeability. Injection of contaminated liquids into a petroleum bearing zone could degrade the resources.

2.4 CONCLUSIONS ON DEEP WELL DISPOSAL

Our review of the Cambrian Formation literature and analysis of existing field data and laboratory results indicates the following:

(1) Disposal of untreated liquids does not appear practical at this time. The chemical variability of these wastes indicates there is significant potential for waste/formation water incompatibility, clogging and well degradation.

(2) Disposal of treated liquids is marginally practical given the liquid volumes expected from the OWMC facility. Due to the moderate permeabilities and thin nature of the Cambrian, disposal will probably be limited to the lower limit of expected liquid volumes (~1 L/s). Some permeable zones capable of handling larger flows do exist but their prediction before drilling and testing is unlikely.

(3) Given this limited practicality, the lack of geologic and hydrogeologic data and the uncertainty about contaminant migration, deep

well disposal does not appear to be a preferred disposal alternative at this time. However, if liquid volumes can be reduced and comprehensive subsurface testing is carried out this may become a viable option in the future.

3.0 LANDFILLS

3.1 INTRODUCTION

This chapter of the report describes four conceptual engineered landfill designs and discusses their hydrogeologic and preliminary geotechnical advantages and disadvantages as disposal options for OWMC's treated waste residue. It is assumed that all of the landfill alternatives will be located in a similar overburden deposit of low permeability. Typical hydrogeologic characteristics of low permeability overburden deposits in southern Ontario are discussed. Historically the major hydrogeologic concern associated with landfilling in low permeability deposits in the humid climate of southern Ontario has been the development of leachate seepages at surface as a result of the 'bath-tub effect'. Another potential concern, albeit less significant, is the potential for lateral movement of contaminants off-site via shallow ground water in the surficial fractured zone generally associated with these deposits. The 'bath-tub effect' and the potential for contaminant migration in the fractured zone are explained in Section 3.3. Each landfill design is discussed with respect to its ability to minimize these concerns, thus providing guidance to OWMC on the viability of landfilling as a disposal option and on the selection and priorization of landfill designs for further study.

3.2 LOW PERMEABILITY DEPOSITS

OWMC has stated that a landfill may be "designed and engineered to the most modern standards but a crucial 'line of defense' must be the natural hydrogeological and geological characteristics" (Ontario Waste Management Corporation, 1982, p. 28). It is presently accepted among most hydrogeologists that low permeability deposits are the preferred materials to provide natural hydrogeologic protection. This is because these deposits:

(1) are aquitards and therefore do not contain significant ground water resources,

(2) ground water flow and contaminant migration rates are slow, maximizing the time available for contaminant degradation and interaction with the soil,

(3) contaminant fluxes are small, minimizing the amount and rate of release of contaminants into the environment,

(4) the attenuating properties of the soils are high providing significant renovation capabilities and delay to contaminant migration,

(5) migration patterns are usually controlled by diffusion and therefore more predictable, allowing greater confidence in determination of future contaminant distribution patterns, and

(6) slow contaminant rates allow more time for implementation of remedial measures should they be required.

In southern Ontario, low permeability overburden deposits mainly consist of glaciolacustrine clays and clayey glacial tills. These deposits usually have an upper weathered and fractured zone, followed at depth by thicker, unfractured soils.

In a study of four till and clay sites in southern Ontario by Desaulniers et al (1981) geochemical evidence suggests the most fractured and dessicated zone to be in the range of 3 to 5 m deep. Based on our experience, this range can be considered typical for most of southern Ontario, although there are some sites that may have significant fracturing to slightly greater depths. For example, two clay sites in southern Ontario investigated by Goodall and Quigley (1977) had significant fracturing as deep as 6 to 7 m. In some cases, isolated fractures may extend even deeper.

Our experience with fractured tills and clays in southern Ontario indicates the saturated hydraulic conductivities of these fractured zones must be determined on a site specific basis. Values may be as high as 1E-06 to 1E-07 m/s. These values are similar to those measured in fractured fine grained soils by Lafleur and Giroux (1983, p454), Griffin et al (1984, Fig. 3), and Grisak et al (1976, p312). However, in some deposits infilling of fractures by expandable clay minerals and/or chemical precipitates may result in much lower hydraulic conductivities (Desaulniers et al, 1981, p236). Effective fracture porosities are estimated to be less than 1%.

Due to the humid climate of Ontario, the water table in fine-grained deposits is usually found within the fractured zone, 1 to 3 m from surface. Where hydraulic conductivities are as high as 1E-06 to 1E-07 m/s, this unit can be considered one of potentially active ground water movement via fracture flow. Where fractures are sealed by clay minerals or precipitates, ground water flow in this zone may not be very active. This requires site specific assessment. Being underlain by an unfractured soil of much lower permeability, the majority of ground water movement is in the fractured unit (with open fractures) and is likely lateral, eventually discharging into nearby surface depressions and surface water courses. At present, the shallow ground water in these systems is not considered a useable resource because of the small volumes and difficulty of retrieval.

Below the 3 to 5 m level the fractures rapidly dissipate with depth and the clays and clayey tills become unfractured. Measurements in Ontario by Desaulniers et al (1981, p236) and Goodall and Quigley (1977, p230) have found the hydraulic conductivites of these unfractured soils to be approximately 1E-10 m/s. As a result, ground water in these materials is not a resource. Ground water velocities are very slow, usually less than 1 cm/a (Desaulniers et al 1981, p240). Therefore the amount of ground water moving to depth is small compared to lateral movement in the fractured zone. A typical schematic of a low permeability deposit in Ontario is shown on Figure 5.

3.3 HYDROGEOLOGIC CONSIDERATIONS ASSOCIATED WITH LANDFILLING IN LOW PERMEABILITY DEPOSITS

Historically the major concern associated with landfilling in low permeability deposits in southern Ontario has been the "bath-tub effect". This occurs when the final cover and waste material is more permeable than the surrounding soils. Thus more water from incident precipitation infiltrates into the landfill than is exiting through its sides and bottom. In a humid climate such as southern Ontario, the result is: the production and build-up of excess leachate within the landfill. If the landfill rises above the surrounding ground surface, the excess leachate may rise into the portion above ground and eventually "spill out" as springs on

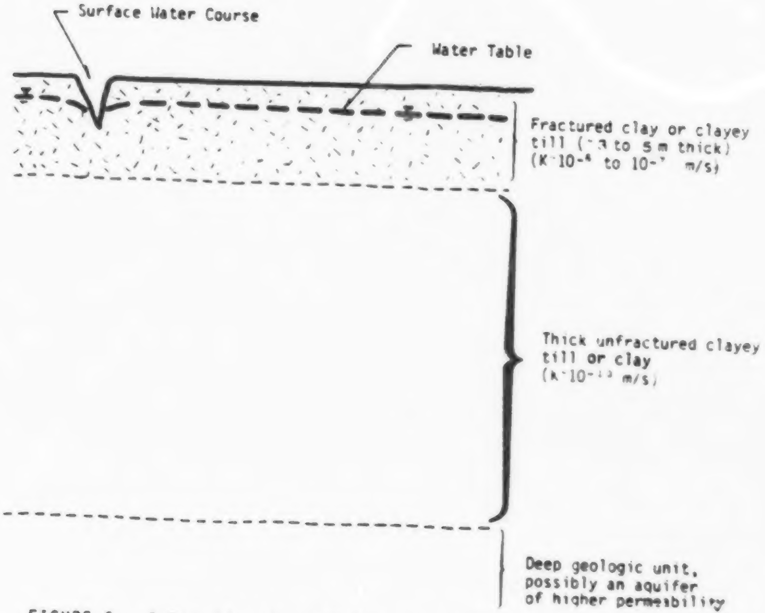

Surface Water Course
Water Table
Fractured clay or clayey till (~3 to 5 m thick) (K~10^{-6} to 10^{-7} m/s)
Thick unfractured clayey till or clay (K~10^{-10} m/s)
Deep geologic unit, possibly an aquifer of higher permeability

FIGURE 5: Schematic of a Typical Low Permeability Deposit in Ontario.

the side slopes of the landfill. These "leachate springs" may potentially contaminate nearby surface waters by overland flow. Leachate springs may also present a potential risk to health from direct human or animal contact.

Another concern associated with landfilling in low permeability deposits is the potential for leachate migration within the fractures of the upper fractured unit (Goodall and Quigley, 1977). Leachate may enter this zone directly from the landfill or by reinfiltration from leachate springs. Since ground water flow in this zone is lateral and locally toward nearby creeks or ponds, this could also lead to potential contamination of the nearby surface waters.

Leachate springs pose a greater potential for concern than migration in the fractured zone. This is because the leachate may have access to surface water directly and rapidly via overland flow with minimal renovation. As well there is the potential for direct contact with vegetation, humans or animals.

In the fractured zone contaminants are expected to be highly attenuated which means they will not move as rapidly within the fractures as advective ground water flow calculations would suggest. This is because of matrix diffusion. As contaminants travel along a fracture, a concentration gradient develops between the solution in the fracture and the solution in the adjacent unfractured matrix. The result is diffusion of the contaminant into the matrix with subsequent loss from the fracture (Feenstra et al 1984, Sudicky and Frind 1982, Tang et al 1981, Grisak and Pickens 1980 and 1981, Grisak et al 1980). This has the effect of substantially retarding and attenuating the contaminant. For example, in a laboratory experiment of chloride movement in fractured till, Grisak et al (1980) found breakthrough of 50% of the original input concentration to be retarded by about 40 times compared to that predicted by using advective fracture flow calculations alone. Since chloride is a conservative mobile contaminant, we can expect even more retardation for non-conservative chemicals and ions. As discussed in Section 1.6.4 the leachate is expected to be mainly inorganic with both conservative and nonconservative ions. The flux of contaminants in the fractured zone will also be significantly reduced if the "effective" hydraulic conductivity is less due to infilling of fractures. The generally aerated environment provided by the near surface and fluctuating water table conditions within the fractures should assist in this process by increasing the precipitation of metal oxides on fracture faces. As well, interconnectivity between many of the fractures is likely poor due to dead end fractures.

To date there has not been a documented case in southern Ontario of significant contamination due to migration of pollutants in the shallow ground water in the fractured zone. However, the majority of work on contaminant migration in fractured soils to date has been in the lab (Sudicky et al, 1983 and Grisak et al 1980 for example). Confirmatory experimental field studies or investigations at existing landfills in southern Ontario have either not been done or have not been published as yet. As a result there is still uncertainty about the attenuating properties within the fractured zone and the potential for contaminant migration to occur within this zone.

With respect to underlying aquifers, landfilling in low permeability deposits should provide little potential for contamination of these ground water resources, if the site is underlain by a substantial thickness of unfractured low permeability soils. Studies by Desaulniers et al (1981) and Goodall and Quigley (1977) have found ground water velocities in unfractured clays and clayey tills of Ontario to be at such slow rates (0.13 to 0.26 cm/a at Desaulniers sites) that solute transport is dominated by diffusion rather than advection/dispersion. Diffusion is a very slow process. For example, using Carbon 14 dating, Desaulniers et al (1981) found the pore water at depths of 20 to 40 m in four clay and clay till deposits of southern Ontario to be in excess of 8000 years old. It was also shown by Desaulniers et al (1981) that the observed depth profiles of the conservative stable isotope oxygen-18 and the conservative anion chloride in the porewater were the result of approximately 10,000 to 15,000 years of diffusion dominated transport. These findings suggest that the ground water near the base of these deposits probably dates back to their origin in the last ice age, approximately 11,000 to 15,000 years ago.

These very slow migration rates to depth provide additional time for the more persistent organic contaminants to be degraded, either biologically or chemically, provided a sufficient thickness of deposit is below the site to maintain long flow times. The higher clay and in some cases, higher organic matter content of the fine grained soils also increases their sorptive capabilities for both inorganic and organic contaminants.

As well, the natural buffering capacity of the carbonate rich soils of southern Ontario will aid in rapid precipitation of the majority of metal contaminants.

Diffusion is a less complicated process than contaminant transport with advection and dispersion. As well, diffusion has been studied in fields other than contaminant hydrogeology for a long time. The result is a higher degree of predictability than for permeable deposits, simpler predictive models, and a larger number of available models for a variety of boundary conditions. (Gillham and Cherry 1982a and b). Using the stable isotope methods of Desaulniers et al (1981) it should be possible at most sites to check, prior to landfilling, whether solute transport will be diffusion controlled. For any mobile, conservative constituents (such as chloride) that may eventually (in thousands of years) reach the underlying ground water resources, diffusion is such a slow process that the diffusion flux should release these contaminants only in small quantities and at very slow rates.

Also relating to the environment surrounding the landfill is the ability to monitor for contaminant movement. Regardless of design, monitoring of the surrounding ground water and soils should be undertaken. If monitoring cannot be done, it restricts our ability to check on the performance of the landfill design and identify the need for remedial measures. Monitoring should be readily achievable in the previously described low permeability deposits using existing technology such as lysimeters, ground water monitors, soil sampling and porewater extraction. One potential concern is the smearing of the fractures during drilling of ground water monitors in the fractured zone. However, a potential solution to this concern would be to use trench monitors. This consists of a trench dug by a backhoe in which the smeared soils on the sides of the trench can be removed manually, exposing the fractures. The trench is then backfilled with granular and a ground water monitoring system.

3.4 LANDFILL DESIGN ALTERNATIVES

From the previous discussion, it appears that, regardless of landfill design, location in a sufficient thickness of low permeability soils should provide considerable natural protection to underlying ground water resources. Consequently, the hydrogeologic suitability of the four landfill designs discussed in the following sections is dependent more on their ability to minimize the formation of leachate springs and, to a lesser extent, minimize lateral leachate migration in the fractured zone, since both of these could potentially result in surface water contamination or direct leachate contact with humans or animals.

The following section describes four landfill designs. It discusses how each design works to minimize leachate spring formation and lateral leachate migration in the fractured zone as well as discussing the advantages and disadvantages of each design. It should be noted however that these designs are not presented as the only designs available. OWMC may for example want to consider an integration of the advantageous aspects of two or more designs. A discussion of all the possible combinations is beyond the scope of this report.

OWMC has stated that any landfill will be "designed and engineered to the most modern standards" (Ontario Waste Management Corporation, 1982, p28). Consequently all landfill designs considered here are engineered landfills. We have divided the engineered landfill designs into two categories relating to the method of leachate control. These are (1) active engineered landfills and (2) passive engineered landfills.

Active engineered landfills use liners, leachate collection systems and final cover - infiltration barriers to control leachate production and control the escape of leachate from the confines of the disposal area.

Passive engineered landfills allow leachate to enter the surrounding soils but in a controlled and predictable manner. The natural containment and attenuation capabilities of the soil are used to control and renovate leachate. A back-up leachate collection system is included as part of the design but is not activated. However, it can be put in use if future monitoring indicates a need for conversion to active leachate control.

3.4.1 ACTIVE ENGINEERED LANDFILLS

Before discussing the two active engineered landfill designs, we should point out that there are presently a multitude of configurations available for each of the active systems. Final cover infiltration barriers currently used on Ontario municipal landfills consist of a few feet of recompacted clayey soils, vegetated and graded to promote runoff. At some hazardous waste sites in the U.S.A. these covers have become highly engineered systems consisting of vegetated and graded surfaces with components such as recompacted clayey soils, synthetic liners and infiltration drainage layers. Historically liners in Ontario have consisted of a few feet of recompacted clayey soils. Present liner designs used at some hazardous waste sites in the U.S.A. consist of synthetic materials (such as plastics) or combinations of synthetic and clay liners to make double or triple liner configurations. When two or three liners are used, drainage layers and collection systems are placed between them. Leachate collection systems can be a series of drainage pipes completely underlying the landfill (an underdrain), a drainage pipe surrounding only the periphery of the landfill (a toe drain or peripheral drain) or a series of collector pipe systems placed between successive liners. Due to the wide variety of active systems designs available, the landfill descriptions given in this section use only the general terms of liner, infiltration barrier and leachate collection system without reference or preference to a specific active system design.

A detailed description, evaluation and comparison of various active system designs is beyond the scope of this report. To provide guidance on choosing appropriate active system designs, we recommend that a detailed evaluation be undertaken as part of the Stage 2 studies. This evaluation should consider factors such as, (1) the landfill design, (2) site specific geology, hydrogeology and geotechnical information, (3) system effectiveness and efficiency, (4) waste and leachate characteristics and interactions, (5) construction practicality, (6) economics, (7) failure scenarios and (8) past performance of similar systems.

Given (1) OWMC's commitment to design and engineer to the most modern standards (Ontario Waste Management Corporation 1982, p.28) and (2) the technologically advanced state of active system design presently available, we have assumed the active systems chosen by OWMC should function as designed over the range of at least a few to several decades, possibly longer. One exception is the infiltration barrier. Although these systems are designed to reduce infiltration as much as possible, it is generally accepted that they cannot completely prevent it. Thus some leachate will always be produced. A noteworthy aspect specific to OWMC that should aid in preventing liner failure is their commitment that no untreated wastes will be placed within the landfill (Ontario

Waste Management Corporation 1982, p. 28). Past failure of both clay and synthetic liners have occurred in the U.S.A. because untreated concentrated organic liquids have altered the characteristics of the liner materials (Green et al 1983).

Because such devices as pumps must be kept operating to remove leachate or silt accumulation in leachate drainage pipes removed, successful continued operation of the active systems in an active engineered landfill will require a long term maintenance program. It is probable, however, that even with maintenance, the active systems will eventually decrease in efficiency and possibly fail. For example, should drainage pipes in the leachate collection system collapse, they would be difficult to replace since they are under the waste mass. From a hydrogeologic and preliminary geotechnical perspective, some advamtages and disadvantages of the two active engineered landfill designs with respect to maintenance of the active systems and their potential failure are discussed in the following sections. Also discussed are the hydrogeologic effects should failure of the active systems occur.

The two active engineerred landfills considered in this report are (1) the active conventional engineered landfill and (2) the active above ground engineered landfill.

3.4.1.1 Active Conventional Engineered Landfill

In the active conventional engineered landfill, the treated waste residues are placed in a shallow excavation, usually less than 10 m deep. For low permeability soils in Ontario this means some of the treated waste residue will be below the water table. The treated waste residues are mounded above ground and covered with a low permeability infiltration barrier to minimize percolation of precipitation. A low permeability liner system is placed below the treated waste residue. If leachate is produced within the landfill, it is removed by a leachate collection system to a sump (or similar arrangement). The leachate collection system is operational; i.e. leachate is pumped out of the sump as required to maintain a minimal leachate head within the landfill. The components of this landfill design are summarized in Table 5.

A functioning active conventional engineered landfill is illustrated schematically in Figure 6. In this design, the leachate collection system maintains a leachate level within the landfill that is lower than the surrounding water table. Thus leachate does not rise within the landfill above the surrounding ground surface minimizing the formation of leachate springs. As well, under these conditions lateral ground water flow is towards the landfill, preventing leachate from moving outward in the shallow ground water of the fractured zone. The final cover-infiltration barrier is used to reduce the amount of water entering the landfill via infiltration. This minimizes leachate production. The liner is used to reduce the inflow of ground water since in this design ground water can interact with treated waste residue below the water table to produce leachate. The liner is also used to increase the efficiency of the collection system and retard the speed at which contaminants may migrate (by diffusion) into surrounding soils.

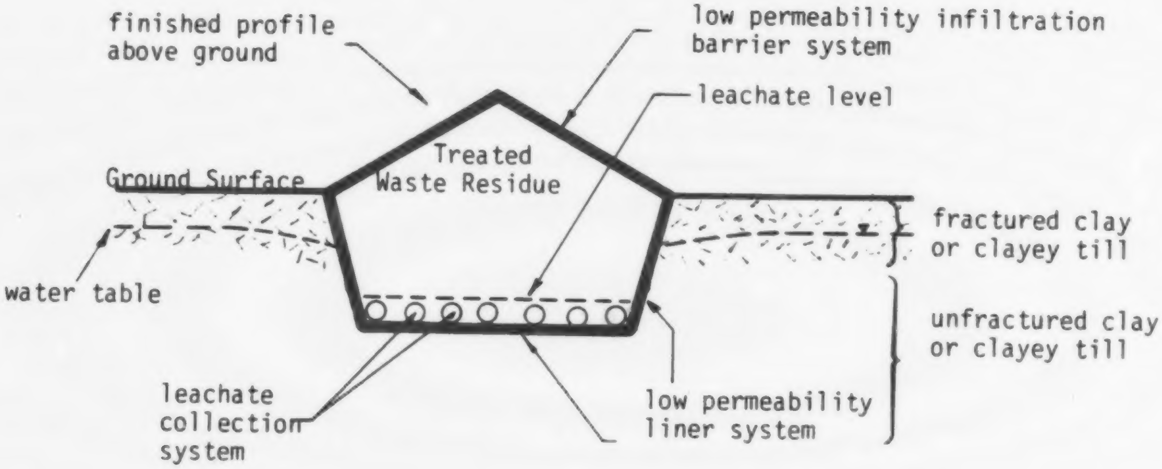
The report by Geraghty and Miller, Inc. (Volume 2) indicates the active conventional engineered landfill to be a common design for new hazardous waste landfills in the U.S.A. This is also the

TABLE 5 Design Components Of Engineered Landfill Alternatives

Landfill Type		Active Engineered		Passive Engineered	
		Conventional	Above-Ground	Deep Entombed	Shallow Entombed
Geologic Setting		within fractured and unfractured clay or clayey till	above fractured and unfractured clay or clayey till	within unfractured clay or clayey till	within fractured and unfractured clay or clayey till
Excavation		shallow	no excavation	either deep excavation or deep caisson holes	shallow
Finished Profile		above surrounding grade	above surrounding grade	approximates surrounding grade	approximates surrounding grade
Material being disposed		treated waste residues only - possibly solidified - no liquids	treated waste residues only -possible solidified -no liquids	treated waste residues only -possibly solidified -no liquids	treated waste residues only -possibly solidified -no liquids
Final cover		infiltration barrier system	infiltration barrier system	compacted clayey soil from surface to top of waste at depth, well below base of frac.zone	compacted clayey soil from surface to at least base of most fractured zone
Liner system - may be synthetic or clay or a combination (multiple barrier)		yes	yes	no	no
Leachate collection system	operational	yes	yes	no	no
	may be present as a future contingency	--	--	yes	yes

Figure 6

Schematic Of Active Conventional Engineered Landfill


finished profile
above ground
low permeability infiltration
barrier system
leachate level
Treated
Waste Residue
Ground Surface
fractured clay
or clayey till
water table
unfractured clay
or clayey till
leachate
collection
system
low permeability
liner system

case in Europe. There are no equivalent hazardous waste sites in Ontario. Modifications of the active conventional engineered design are common for new sanitary landfills within Ontario located in low permeability deposits. Generally these sanitary landfills have leachate collection and cover systems but do not have a liner.

In an attempt to evaluate the performance of some existing sites, Geraghty and Miller Inc., collected data from 3 active conventional engineered landfills (Scientific, Toms River and J.T. Baker) and 3 modifications of this design (unlined but with a leachate collection system) (Kettleman, Emelland Florence) (see Volume 2). All but 2 were in clayey soils or glacial tills. In all but one site (Florence) the wastes were placed above the water table. All of these sites are less than seven years old and therefore do not provide an indication of long term performance. As well, Geraghty and Miller Inc. did not do an independent evaluation of the monitoring data. However, the results do provide some useful information. The collected monitoring data showed no ground water or surface water impacts from any of the sites located above the water table. However, at two of these sites (Toms River and J. T. Baker), both with 2 PVC liners, the upper liner was found to be leaking. Both of these sites were developed in 1977. The cause of the leaks are unknown. However, untreated industrial wastes are disposed at both sites and there do not appear to be leachate collection systems above the first liner (they are between the two liners). At the one site in which wastes are below the water table (Florence, an unlined site in a clay deposit) the monitoring data show there has been minimal migration of contaminants into the surrounding clayey soils. However, the leachate collection system was not operated correctly resulting in a buildup of excess leachate and leachate springs.

Advantages of the active conventional engineered landfill are:

(1) Provided the active systems are functioning properly, the active conventional engineered landfill should minimize leachate production and collect any leachate produced. Thus leachate spring formation and release of leachate into the soils and ground water beyond the landfill limits should be minimal.

(2) This is a common landfill design presently in use at the majority of hazardous waste landfills.

(3) Minimizing movement of leachate into the surrounding soils allows leachate to be collected, tested and treated, if required, until it is acceptable for release to the environment.

(4) This design will continue to minimize leachate spring development and lateral movement in the fractured zone even if the liner and infiltration barrier fail. This is provided the leachate collection system continues to operate, maintaining a low leachate level within the landfill.

(5) By the time a significant deterioration of the active systems occurs; (a) the amount of contaminants in the treated waste residue mass and therefore the strength of the leachate may have been reduced or (b) new technologies may have developed to further process or reclaim the residues.

(6) If leachate escapes due to failure of the active systems, the surrounding low permeability deposit acts as a second line of defense to protect underlying ground water resources.

(7) Two levels of hydrogeologic monitoring can be used. First, the active systems can be monitored directly to determine if they are functioning correctly. An example would be monitoring for the presence of leachate in a drainage layer between two liners to evaluate primary liner performance. Secondly, the ground water in the surrounding soils can be monitored to determine if any leachate is migrating out of the site and if so, what the potential impact may be.

(8) There are no major geotechnical constraints to construction since the excavation is shallow and uses conventional construction techniques.

(9) Remedial measures, should active system failure occur, might first be resolved through repair of the active systems, before implementation of remedial measures in the surrounding soils, ground water or surface water are required.

Disadvantages of the active conventional engineered landfill are:

(1) Continued function of the active systems requires a long term operation and maintenance program. Of special note for this design is the requirement to keep pumps operating to remove leachate from the collection system.

(2) It is impractical to repair or replace the liner because it is buried under the waste mass. The leachate collection system is also difficult to maintain and impractical to replace because it is located under the waste mass.

(3) Should the active systems fail, especially the leachate collection system, a buildup of excess leachate will occur. Because the finished profile extends above grade, the excess leachate can also rise above the surrounding ground surface. Thus leachate springs may develop on the side slopes of the landfill and/or leachate flow could occur laterally outward in the fractured zone.

(4) While the infiltration barrier should reduce infiltration it is likely that it can not completely stop it. Consequently some leachate will probably always be produced. As well, because this landfill design is located below the water table, a leak in the liner would result in ground water seepage into the site, which in turn would produce leachate.

(5) As long as leachate is being produced, collection will be required. This may be hundreds of years, over which time it is probably impractical to maintain the system.

(6) All collected leachate may require treatment.

(7) Deterioration of the infiltration barrier allowing increased infiltration could result in a substantial volume of leachate to be collected and treated.

3.4.1.2 Active above ground engineered landfill

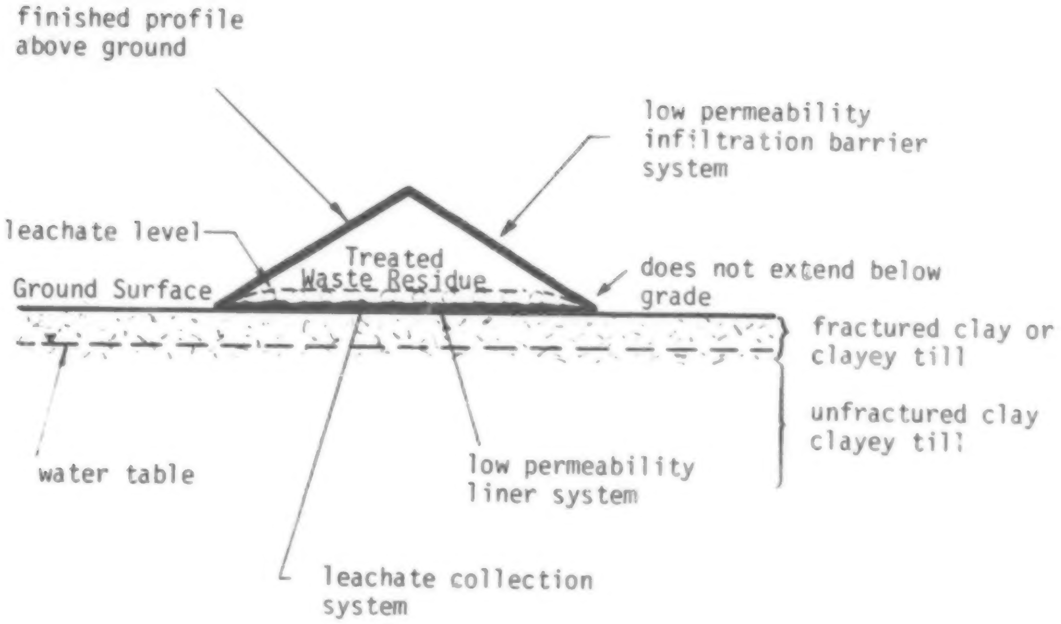
The active above ground engineered landfill involves encapsulation of the treated waste residue above grade and therefore above the water table. A low permeability liner is placed below the treated waste residue, combined with a low permeability infiltration barrier as final cover. If any leachate is produced it is continuously removed along a sloped bottom by a gravity leachate collection system. The components of this design are summarized in Table 5.

A functioning above ground engineered landfill is shown schematically in Figure 7. In this design any leachate produced within the landfill is prevented, by the liner, from escaping out the bottom into the fractured zone. The liner directs the leachate to the leachate collection system. The leachate collection system is designed to prevent excess leachate levels from accumulating and forming leachate springs. The final cover-infiltration barrier is used to minimize the amount of leachate produced by minimizing infiltration.

The above ground landfill is a relatively new concept. It appears to have been originally developed for on-site remedial storage and/or disposal of wastes that had originally been disposed in a poor hydrogeologic environment. Most references in the literature consider the design as an approach to waste storage rather than permanent disposal (Brown and Anderson 1984, Bridge 1982, Bridge et al. 1982). However, some references are suggesting the above ground landfill as a permanent disposal option (Brown 1983 and Brown et al, 1983a and b for example). In their conversations with various regulatory agencies and waste disposers in the U.S.A., Geraghty and Miller, Inc. found significant interest towards use of the above ground landfill for permanent hazardous waste disposal.

Figure 7

Schematic Of Above - Ground Engineered Landfill


finished profile above ground
low permeability infiltration barrier system
leachate level
Treated Waste Residue
Ground Surface
does not extend below grade
fractured clay or clayey till
unfractured clay clayey till
water table
low permeability liner system
leachate collection system

Geraghty and Miller Inc. (see Volume 2) collected data from 3 above ground landfills (CECOS, Dupont and Anonymous). Two of these designs have 3 liner systems (2 clay and 1 synthetic) and one has a two liner system (synthetic).

The collected monitoring data showed no ground water or surface water impacts at any of the sites. At two sites (DuPont and Anonymous) the first liner is leaking. The cause of the leaks are unknown, however, both sites accept untreated solid industrial wastes.

All of the sites are less than six years old and therefore do not provide an indication of long term performance. As well, Geraghty and Miller Inc. did not do an independent evaluation of the monitoring data.

Most of the advantages of the above ground engineered landfill are the same as the active conventional engineered landfill outlined previously. These are numbers (1), (3), (5), (6), (7) and (9) in section 3.4.1.1. One additional advantage specific to this design is;

(1) Because the leachate collection system is above grade it can be designed to drain off leachate without pumps, reducing operation and maintenance requirements. The leachate collection system is also more accessible for maintenance when it is above ground (Brown 1983).

Disadvantages of the above ground engineered landfill are;

(1) Continued function of the active systems requires a long term operation and maintenance program.

(2) It is impractical to repair or replace the liner because it is buried under the waste mass. Although the leachate collection system may be more accessible for maintenance it is still impractical to replace because it is also under the waste mass.

(3) While the infiltration barrier should reduce infiltration it is likely that it can not completely stop it. Consequently some leachate will probably always be produced. Deterioration of the infiltration barrier, allowing increased infiltration, would result in a substantial increase in the volume of leachate collected and treated.

(4) Should the leachate collection system fail a buildup of excess leachate will occur resulting in leachate springs on the side slopes of the landfill.

(5) Should the liner deteriorate leachate will leak out the bottom of the landfill by gravity into the underlying fractured zone, even if the leachate collection system is still functioning (Kmet et al. 1981).

(6) Because the bottom of the landfill is above the water table, desiccation is an additional process that may contribute to deterioration of a liner, if comprised of clay.

(7) Differential settlement, especially in glaciolacustrine clays, is an additional factor in this design that may speed failure of the liner, cover material and collection system. In the above ground design the load beneath the

sideslopes is transitional i.e. there is more weight in the centre of the landfill than at the sides. Little or no compression of the desiccated crust will occur, however, the load may be transferred to the deeper, softer, normally consolidated clays. This will result in more settlement beneath the centre of the fill with less settlement at the toe. Settlement should be less of a problem in over-consolidated glacial tills.

(8) As long as leachate is being produced, collection will be required. This may be hundreds of years, over which time it is probably impractical to maintain the system.

(9) All collected leachate may require treatment.

3.4.2 PASSIVE ENGINEERED LANDFILLS

It is possible to design engineered landfills in low permeability deposits that do not use active systems. Instead leachate is allowed to migrate in a predictable and controlled manner. Natural attenuation processes are used to renovate the leachate, therefore minimizing the risk to surface and ground water resources.

To confirm that these processes are minimizing contaminant movement, monitoring of the surrounding ground water and soils is essential to the safe implementation of this design. Although there may be some uncertainties associated with this approach passive engineered landfill designs have the advantage of reducing the need for long term maintenance of active systems and more importantly they minimize some of the concerns associated with active landfills should their active systems fail, especially leachate springs.

Two design options; the passive deep entombed engineeered landfill and the passive shallow entombed engineered landfill, are discussed in the following sections.

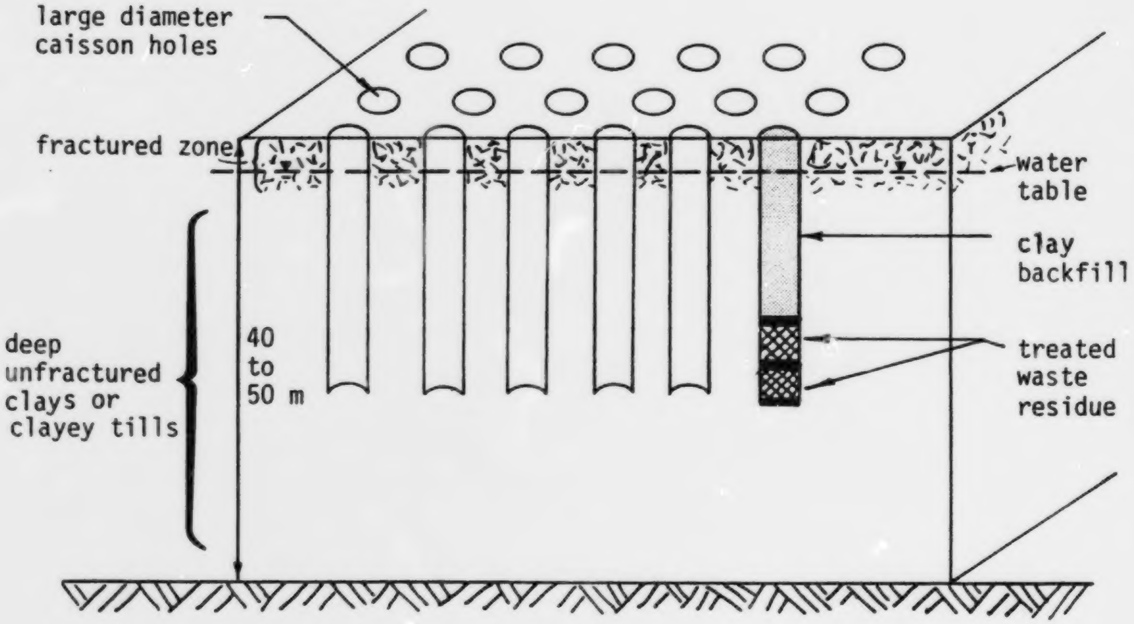
3.4.2.1 Passive deep entombed engineered landfill

This disposal option involves the placement of treated waste residues deep in the unweathered and unfractured zone of the low permeability soils. The treated waste residues remain well below the upper fractured zone. A clayey soil or equivalent backfill is used above the waste with the site being finished flush to ground surface. Two approaches are possible; (1) deep, large diameter caisson holes as proposed by Cherry et al. (1979) and (2) a deep, open excavation. The components of this design are summarized in Table 5 and shown schematically in Figures 8 and 9.

This concept does not rely on active systems because the entire mass of treated waste residue will be surrounded by significant thicknesses of unfractured low permeability clayey soils. If properly compacted the clayey soil backfill placed over the landfill should remain unfractured at depth because of its considerble weight and thickness and because the majority of it will be below the water table, away from the zone of desiccation (Cherry et al. 1979). Under these conditions migration of contaminants away from the treated waste residues will be predominantly by diffusion. There is no potential for leachate springs to form or for leachate to enter the upper fractured zone since the treated waste residue is located well below ground and the bottom of the active fractured zone. As discussed in section 3.3, when contaminant movement is controlled by diffusion, migration rates are very slow, allowing maximum time for attenuation and degradation processes to remove contaminants. This is com-

Figure 8

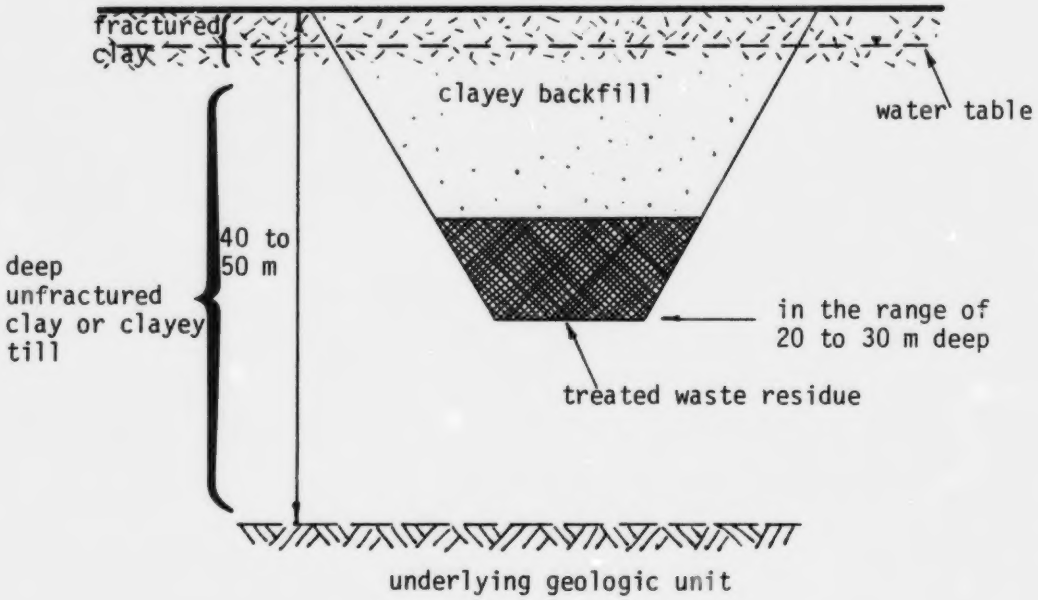
Schematic Of Deep Entombed Engineered Landfill Caisson Hole Approach


large diameter caisson holes
fractured zone
water table
clay backfill
deep unfractured clays or clayey tills
40 to 50 m
treated waste residue

Underlying geologic unit

Figure 9

Schematic Of Deep Entombed Engineered Landfill - Excavation Approach


fractured clay
clayey backfill
water table
40 to 50 m
deep unfractured clay or clayey till
in the range of 20 to 30 m deep
treated waste residue
underlying geologic unit

pounded by the higher natural attenuation and buffering properties of the clayey soils. Although some conservative contaminants (those that are not appreciably attenuated or reactive such as chloride) may eventually reach the surface or underlying ground water resources, (in hundreds or thousands of years) the amount and rate of release will be small. It is assumed that the fluxes released would be small enough to be accepted into the surface environment or into the aquifer without significant impact. Confirmation that the landfill was performing as discussed above would require an extensive long term monitoring program.

In our review of the literature we did not encounter a waste disposal facility either past or present, that has used either the caisson hole or deep excavated entombed engineered landfill concept. A deep caisson hole was drilled in western Canada as a follow up to the Cherry et al. (1979) study to show that the concept was feasible. However, no wastes were placed in this hole.

Preliminary calculations show that the caisson hole method is likely not practical given the uncertainty about the volumes of treated waste residues the OWMC facility may produce for landfill disposal. Assuming 3 m diameter holes, with wastes placed between a depth of 10 and 30 m, each hole could accept 141 cubic m of waste. As outlined in section 1.6.1 the annual treated waste residue volumes may vary from 150,000 cubic m/a to 420,000 cubic m/a. This would require the drilling of anywhere from 1064 to 2979 holes per year. We have estimated it will take, at a minimum three days to drill and inspect each hole. Another day or two will be required to seal the holes after they have been filled. With these time constraints drilling one to three thousand holes per year is probably not practical.

There are some major geotechnical constraints with the deep excavation concept. Given the depth, there is concern about the stabiility of the base because of the potential for blowout. Blowout is created by ground water under pressure, in a water bearing zone beneath an excavation, exerting sufficient upward pressure to cause a fracturing of the soil followed by an upheaval of water and soil into the excavation. After blowout occurs major dewatering is required to continue the excavation. The potential of blowout is reduced if the underlying unit does not contain significant hydraulic heads. This of course is site specific. In the situation where upward pressures are being exerted, the closer the excavation bottom is dug to the water bearing zone, the greater the chances for blowout. The major resisting force to blowout is the weight of the overlying soil. Consequently, it may be possible to maintain a sufficient depth of soil below the excavation to prevent blowout, provided the deposit is very thick. This would have to be assessed on a site specific basis. Once geotechnical, stratigraphic and hydrogeologic data are collected it is possible to evaluate blowout potential. Another approach to preventing blowout is to pump the underlying aquifer to reduce its hydrostatic pressure. However, pumping is a potentially troublesome approach since it may cause wide scale interference with nearby water wells, as well as produce a large amount of water which must be handled.

Slope stability is another concern in the deep excavation approach, especially if the soils are glaciolacustrine clays. To obtain stability it is expected sideslopes would have to exceed 3:1, even in the tills.

Advantages of the deep entombed engineered landfill are;

(1) Without using active systems the potential for leachate springs to form and for leachate to enter the fracture zone is small.

(2) Migration of contaminants away from the site in all directions should be dominated by diffusion, a very slow process. This diffusion occurs into a highly attenuating soil medium. Consequently the potential for contaminants to migrate to, and have an impact on surface or on underlying aquifers is small.

(3) The landfill should not require long term maintenance.

(4) There is no leachate handling or treatment since leachate is not collected.

Disadvantages of the deep entombed engineered landfill are;

(1) The practicality of drilling a sufficient number of caisson holes for the projected treated waste residue quantities is a major constraint for this type of deep entombed engineered landfill.

(2) The potential geotechnical concerns of bottom blowout and side slope stability are major constraints for the excavated entombed engineered landfill.

(3) There are no existing landfills of this type, therefore this design is unproven in practise.

(4) Extensive ground water and soil monitoring would be required over the long term to confirm the predictions

of slow, diffusion controlled contaminant migration with high attenuation.

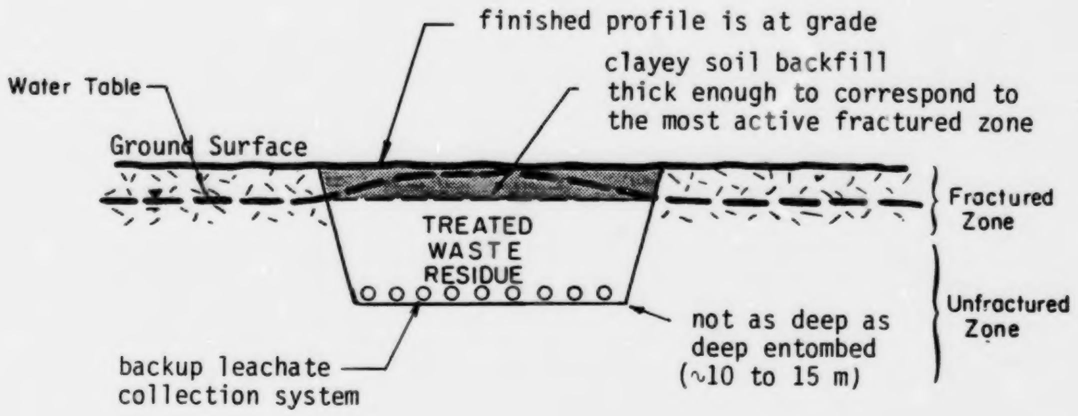
3.4.2.2 Passive Shallow entombed engineered landfill:

This alternative design is similar to the excavated deep entombed landfill except the excavation is shallower and at more conventional depths (approx. 10 to 15 m). A design utilizing a shallower excavation is proposed to avoid the major geotechnical concerns associated with the excavation of the deep excavated entombed engineered landfill (see section 3.4.2.1). A clayey soil is used as backfill over the treated waste residue. The thickness of the backfill corresponds to or exceeds the thickness of the zone of most active ground water movement in the fractures (ie. about 4 m). The landfill is finished flush to surface. A backup leachate collection system is installed but not activated. The components of this design are summarized in Table 5 and shown schematically on Figure 10.

The underlying philosphy of this design is to minimize the potential for leachate springs by not raising the finished profile above the surrounding ground level. Since the treated waste residue is placed below the level of most active ground water flow in the fractures, direct access and lateral movement of leachate in this zone should be minimized. Since the backfill will probably be more permeable than the surrounding soils, excess infiltration will cause a water table mound to be present within the landfill as shown on Figure 10. This may result in some lateral movement of ground water outward from the landfill in the fractured zone. However, because the treated waste residues are below the most active portion of the fractured zone, the majority of this lateral ground water movement will be relatively uncontaminated water infiltrated from above that has not con-

Figure 10

Schematic Of Shallow Entombed Engineered Landfill


finished profile is at grade
clayey soil backfill
thick enough to correspond to
the most active fractured zone
Water Table
Ground Surface
Fractured Zone
TREATED WASTE RESIDUE
Unfractured Zone
not as deep as deep entombed (~10 to 15 m)
backup leachate collection system

Not To Scale

tacted the treated waste residue. Any leachate or contaminated ground water that may enter the lower portions of the fractured zone will likely be highly attenuated by matrix diffusion (see section 3.3). However, an extensive ground water and soil monitoring program would be required in the fractured zone, to confirm whether contaminant movement is minimized or not. Should future monitoring identify potential problems associated with contaminants migrating in the fractured zone the backup leachate collection system could be activated. This active system could draw the leachate within the landfill down to a level below the surrounding water table similar to the active conventional engineered landfill. Thus lateral ground water flow in the fractured zone would be towards the landfill rather than away. With the landfill bottomed in a signifcant thickness of unfractured low permeability soils, migration to depth with or without the collection system active, would be predominantly by diffusion, thus protecting underlying aquifers (see section 3.3). This too would have to be confirmed by monitoring.

This design is not common in humid climates such as southern Ontario. One example however, is the Tricil landfill in Corunna, Ontario. In dry climates, where the water table is deep (such as the southwestern USA) shallow, passive engineered landfills are more common because infiltration is minimal and the waste can be maintained well above the water table. Thus leachate production and movement is minimal.

To date there have not been any ground water or surface water concerns identified at the Tricil landfill in Corunna (Ontario Ministry of the Environment, pers. comm.). However, this landfill is less than five years old and therefore is not old enough yet to provide information on long term performance. One controversial site looked at by Geraghty and Miller, Inc. is the Wilsonville landfill in Illinois (see Volume 2). This site is a shallow entombed landfill in a glacial till environment that has been ordered exhumed. However, this exhumation was due mainly to social and political reasons rather than environmental reasons (Johnson, pers. comm.). Apparently the site is located very close to housing developments and contains barrelled wastes of concentrated organic liquids. There has been no contamination of ground or surface water resources (Johnson, pers. comm.) although some organic contaminants have been detected at low concentrations (parts per billion) in the shallow soils short distances from the site (Griffen et al. 1984). Due to the relatively low permeability of the tills and fractured tills the ground water in the slightly contaminated soil zones is not a resource. It is presently unknown whether the contaminant migration is due to movement along fractures or is due to movement through thin sand layers found within the soils at the site. This landfill is not considered a representative site upon which to evaluate the passive shallow entombed engineered landfill as proposed in this report because;

(1) the Wilsonville landfill is developed in more permeable sandy tills, which contain sand seams.

(2) the fractured zone is deeper and more developed than in Ontario because the tills are much older.

(3) the waste materials at Wilsonville are concentrated liquid organics, while the materials in OWMC's landfill will be only treated waste residues, generally of an inorganic nature.

The advantgages of the shallow entombed engineered landfill are;

(1) Without using active systems the potential for leachate springs to form and for leachate to enter the fractured zone should be much less than would occur should the active engineered landfill designs fail. This is because the finished profile of this landfill does not rise above grade and the wastes are kept below the active fractured zone.

(2) Migration of contaminants to depth should be highly attenuated and controlled by diffusion, a very slow process. Thus the potential for contaminants to migrate to and have an impact on underlying aquifers is small.

(3) The landfill when acting passively may not require long term maintenance.

(4) There is no requirement for leachate handling or treatment when the landfill is acting passively.

(5) Should future monitoring indicate potential concerns associated with lateral leachate movement in the fractured zone, the backup leachate collection system can be activated.

(6) Due to its shallow depth geotechnical constraints to its construction should be minimal. However this will depend on site specific conditions.

The disadavantages of the shallow entombed engineered landfill are;

(1) There are uncertainties associated with how much leachate may enter the fractured zone and what impact this will have.

(2) Since we did not evaluate this design through hydrogeologic modelling or field evaluation of existing sites, the possibility of minimal leachate seepages at surface has not been confirmed.

(3) There are very few engineered landfills of this type in humid climates such as Ontario to provide information on performance, especially long term.

(4) Extensive ground water and soil monitoring would be required over the long term to confirm that the landfill is performing as predicted.

(5) Should the leachate collection system need to be operated then long term maintenance will be required and there will be leachate to be handled and possibly treated.

3.5 REGULATORY PERSPECTIVE

Review and discussion with the Ontario Ministry of the Environment did not indicate any Ontario waste disposal regulations that preclude any of the previously discussed landfill designs. The underlying regulatory philosophy towards landfilling in Ontario is to evaluate each proposal on a site specific basis. If a particular design can be proven effective in protecting ground and surface water resources then it meets regulatory criteria, at least on hydrogeologic grounds. The existing preference is toward locating in low permeability soils. The Ministry of the Environment expressed some concern about the deep entombed concept because it has not been tried before and its excavation places the treated waste residue closer to the underlying aquifer. They were also concerned about any design that may eventually have leachate spring breakout unless long term care was being provided.

Discussions with regulatory personnel across Canada revealed similar approaches to landfill approval and similar concerns about the landfill designs considered here.

Geraghty and Miller, Inc. reviewed hazardous waste disposal regulations in the USA (see Volume 2). The regulatory trend there is for either ; (1) passive engineered landfills, above the water table in fine grained soils and dry climates or (2) active engineered landfills. Note that the USA regulations do not address passive engineered landfills in low permeability deposits where the wastes are below the water table. In areas of humid climate, the trend has been to require active engineered landfills.

3.6 CO-DISPOSAL IN A MUNICIPAL LANDFILL

For the purposes of this study we have assumed co-disposal means placement of OWMC's treated waste residues within an existing municipal landfill either by mixing with the municipal waste or placing it in separate cells. The purpose of this section is not to identify potential municipal landfills within southern Ontario at which co-disposal could be undertaken. Rather, this section outlines some of the advantages and disadvantages of co-disposal from a generic sense.

The main hydrogeologic advantage to co-disposal is that the existing municipal landfill can be used as a valuable case history to determine if the surrounding environment is being contaminated by the landfilling process.

However, where treated waste residues are disposed within an existing municipal landfill, the future hydrogeologic impact of these residues will be dependent on the past hydrogeologic siting and operating criteria used to develop and maintain the municipal landfill. These criteria may not have been the same or as stringent as the OWMC criteria. The composition of leachate collected from municipal landfills usually allows direct discharge to a sewage treatment system without further treatment. However, addition of OWMC's treated waste residues, especially if mixed with the refuse, may result in contaminated leachate requiring treatment. For example, the acidic nature of domestic landfill leachate may increase the amount of metals leaching from the generally inorganic treated waste residues. Thus OWMC might have to collect and treat leachate produced by both their treated waste residues and the municipal refuse. Given the variable nature of domestic refuse direct mixing with treated waste residues could also result in chemical incompatability reactions, although this is probably unlikely due to the generally inorganic nature of the treated waste residues. If a contamination problem develops at the landfill it may be difficult to discern if this is due to the domestic refuse or OWMC's treated waste residues. Finally, placing municipal wastes and treated waste residues together on the same site will result in increased waste volume. This is a potential problem since the size of existing municipal landfills have been based on projected waste quantities from within their own municipality only.

3.7 CONCLUSIONS AND RECOMMENDATIONS

3.7.1 CONCLUSIONS

The following conclusions can be drawn from the previous discussions on landfilling. It should be recognized that these conclusions are based on a review and qualitative analysis of existing literature only.

(1) The major hydrogeologic concerns associated with landfilling in low permeability deposits in Ontario are leachate springs and, to a lesser extent, lateral movement of leachate in the shallow ground water of the fractured zone. These can potentially lead to surface water contamination or direct human or animal contact with leachate.

(2) Contamination of underlying ground water resources is less of a concern because it is assumed all designs will be underlain by a sufficiently thick sequence (site specific) of unfractured low permeability soils. Contaminant flow rates and fluxes are very small in these soils and attenuation capabilities are high.

(3) From (1) and (2) above, the hydrogeologic viability of the landfill designs is dependent on their ability to minimize leachate springs and, to a lesser extent, leachate movement into the fractured zone.

(4) From hydrogeologic and preliminary geotechnical aspects

the active conventional engineered landfill, the above ground engineered landfill and the passive shallow entombed engineered landfill, when located in low permeability soils, all appear to be potentially viable disposal options for OWMC's treated waste residues.

(5) Deterioration or failure of the active systems in either active engineered landfill design may result in leachate springs and an input of leachate to the fractured zone. Consequently, these landfills will probably require long term maintenance. On the other hand, while the active systems are functioning escape of leachate at surface or into the surrounding soils will be minimal. Continued operation of these systems for as long as possible (a) allows leachate to be collected and treated, if required, before release to the environment, (b) may provide sufficient time for the waste mass and leachate strength to decay and (c) may delay release of contaminants until new technologies are available for further processing of the treated waste residues.

(6) With the shallow entombed landfill there is a potential for some leachate diffusion into the fractured zone and possibly at surface. However, this would be much less than would occur upon failure of the active engineered landfill designs. If the potential for leachate impact from the shallow entombed engineered landfill is determined to be small, because of the small amounts released, then this landfill design may reduce the need for long term maintenance. If leachate impact is a concern the backup leachate collection system can be used

to operate the design as a modified active landfill design.

(7) The deep excavated entombed engineered landfill may have limited practicality due to potentially serious geotechnical concerns such as bottom upheaval and slope stability. The seriousness of these concerns will be site specific. If, based on site specific information, no geotechnical constraints are identified then this landfill design may be a potentially viable disposal option.

(8) Based on the assumed treated waste residue volumes the caisson hole approach to the deep entombed engineered landfill does not appear practical due to the large number of holes required. However, if treated waste residue volumes can be substantially reduced this method offers equivalent containment to the deep excavated entombed engineered landfill without the associated construction concerns.

(9) None of the four designs were limited by regulations of the Ontario Ministry of the Environment provided it could be shown they worked on a site specific basis. The Ministry of Environment did however express concerns about the deep entombed engineered landfill designs because (a) they may not be practical, (b) they are unproven in practice and (c) they place wastes deeper towards underlying aquifers than the other designs.

(10) Co-disposal within an existing municipal landfill has the advantage of using the existing landfill as a

case history to determine landfilling impacts. However the following are considered significant constraints to co-disposal as a viable option; (1) differences in siting operating and engineering criteria between OWMC and the existing landfill, (2) potential incompatibility between some municipal wastes and the treated waste residues, (3) changes in leachate chemistry that may require treatment of all leachate, even that produced by the domestic waste and (4) the need to find an existing site presently large enough to accept both municipal waste and OWMC's waste residues.

3.7.2 RECOMMENDATIONS

(1) The active conventional engineered landfill, the above ground engineered landfill and the passive shallow entombed engineered landfill should all be considered for further evaluation in stage 2 studies.

(2) Considerable evaluation has already been completed on landfilling as a disposal option, especially with respect to locational aspects. However from a hydrogeologic and geotechnical perspective further evaluation of the landfill designs in stage 2, to aid in specific design decisions, should include;

(a) both generic and site specific hydrogeologic modelling of each design,

(b) hydrogeologic modelling of various active systems both generically and with site specific input,

(c) a more complete hydrogeologic and geotechnical evaluation of active system designs and the reasons for their success or failure in general terms and based on site specific information,

(d) collection of detailed monitoring and performance data from company or government files to evaluate the performance of various existing landfill designs in humid climates and low permeability soils.

(3) The above evaluation (stage 2) should be integrated with other aspects such as engineering feasibility, social impact, land requirements, air pollution and economics.

(4) If it is possible to reduce the volume of treated waste residues such that the caisson hole method is practical, then this design should also be included in the above stage 2 studies.

(5) If site specific information does not identify major geotechncial constraints to the excavated deep entombed engineered landfill then this design should also be included in the above stage 2 studies.

4.0 LAND TREATMENT

Land treatment is the application of specific types of wastes onto the soil where the waste characeristics allow them to be degraded and attenuated by natural processes in the soil such that repeated waste applications can be made without environmental impact and without a significant buildup of contaminants or residues. This is considerably different from landfilling where waste volume accumulates because the amount and types of wastes are not amenable to complete degradation during the disposal period.

For the purposes of this evaluation it is assumed that any land treatement site will be located in a low permeability deposit. A description of low permeability deposits in southern Ontario and their advantages for protecting surface and ground water resources is given in section 3.2. Land treatment in permeable deposit was not considered for the following reasons:

(1) Permeable deposits can contain significant ground water resources. Should land treatment in this environment result in contamination of the ground water it could mean a direct loss or impairment of this resource.

(2) In permeable deposits conservative contaminants such as inorganic anions, neutral metal complexes and some potentially harmful organics from landfills have been observed to infiltrate to the water table and be transported long distances in the ground water at rapid rate without significant renovation (see Dewalle

and Chian 1981, Kimmel and Braids 1980, Reinhard et al. 1983 for examples). In many cases contaminated ground water has discharged to and impaired surface water. Similar problems could potentially develop at land treatment sites.

(3) Very little is presently known about contaminant degradation and attenuation in the unsaturated zone. However, the time available for degradation before contaminants infiltrate to the water table and the attenuation capabilities of permeable soils are considered to be much less than in low permeability soils.

(4) Difficulties in obtaining measurements of all the parameters required make it at present difficult to predict contaminant movment in the unsaturated zone and saturated zone of permeable deposits.

(5) Due to the rapid infiltration and ground water flow rates in permeable deposits the lead time between contaminant detection and implementation of remedial measures is short.

There are generally two operation methods for land treatment in low permeability soils. These are irrigation and landfarming.

Irrigation is used for the disposal of liquids only. Generally, these liquids are irrigated by overland flow, the trench method, or spraying. In the overland flow method the liquid wastes are sprayed on shallow vegetated slopes, allowed to run overland and then collected. The wastes are renovated by evaporation, interaction with the vegetation, and infiltration where they undergo degradation and attenuation. The trench method places wastes in a shallow network of trenches where evaporation and degradation/attenuation of infiltration is used to renovate the wastes. Spray irrigation sprinkles the waste on a generally flat sometimes vegetated surface where evaporation, interaction with the vegetation and degradation/attenuation of infiltration is used to renovate the wastes.

In landfarming, waste sludges are periodically (three or four times a year) spread on the soil surface and then mixed with the top several centimetres of soil by tilling. Biodegradation is the major process in landfarming to (1) decompose the solid residues and prevent their accumulation on surface and (2) destroy contaminants before they are carried to ground and surface water resources. Secondary processes, such as sorption and chemical precipitation, are used to attenuate the low levels of inorganic contaminants (usually metals) and non-biodegradable organics.

A recent report on land treatment of hazardous wastes by M.M. Dillon Ltd. (1984) divides land treatment into two categories as follows;

"i) using the land for agricultural purposes where the waste acts as a nutrient or soil supplement;

ii) using the land application site solely for waste disposal.

The first type has been used extensively for municipal sewage sludges and food processing wastes (35). In this case, the limiting factors for the waste being land applied are its nutrient content and its toxicity, either to the crops or to the consumers of the crops. Properties such as toxicity, bioaccumulation factor, food chain effects, and phytotoxicity, have, in general, been considered in the setting of standards for sewage sludge land application. Limitations have been applied for properties such as the concentration of contaminants and nutrients in sludges or the quantity to be applied per hectare of land.

Most wastes classifiable as "hazardous" will exceed some of the standards for appplication to agricultural land. For these wastes, disposal is the sole purpose of the land application site and soil micro-organisms are used as a treatment or disposal agent rather than as an aid to crop production. In this case, waste application is not limited by effects on crops and consumers but only by the effects on the environment." (M.M. Dillon 1984, p.3-1).

This report will discuss the second category of land treatment since municipal waste waters, municipal sewage sludges and food processing wastes are not deemed hazardous wastes for acceptance at the OWMC facility (Ontario Waste Management Corporation 1982, Appendix B). In Ontario all irrigation sites and the majority of landfarming operations dispose of municipal waste waters, municipal sewage sludges and food processing wastes. The only hazardous waste land treatment presently in use in Ontario is landfarming of petroleum refinery wastes. There are presently about a half dozen landfarms at refineries in Ontario. No monitoring data was available for these landfarms to determine their performance. A case history reported by Norris (1980) for a refinery waste landfarm in Sarnia, Ontario found biodegradation to adequately and rapidly degrade the waste with trace metals strongly sorbed in the uppermost soil layer. In the USA the majority of hazardous waste land treatment operations dispose of petroleum refinery wastes, with a small percentage disposing of a large variety of other hazardous biodegradable wastes (K.W. Brown and Associates, 1981). Land treatment has been incorporporated into hazardous waste treatment faclities at some locations in the USA (Hrudey 1983b). A typical example is the Kettleman Hills facility in California described by Geraghty and Miller, Inc. in Volume 2.

The underlying philosophies of a successful land treatment site are:

(1) that run-off is minimized, to protect surface waters,
(2) that the waste is mostly biodegradable,
(3) that the infiltrating waste is biodegraded and renovated before it reaches the underlying ground water resources
(4) that waste volume does not accumulate on the land surface, and
(5) that the soil does not become so contaminated that it can not be utilized for other purposes in the future.

Run-off is readily conrolled by proper application rates, berming and ditching. Applications in southern Ontario are limited by cold temperatures, frozen ground conditions and wet, inclement weather. Experience in Ontario indicates that there are only about 100 to 120 operable days, mostly in the summer, in which landfarming and irrigation can be conducted (Norris 1980, Van Fleet 1977). Facilities are required for liquid and sludge storage at other times.

Before implementation of a land treatment site a test plot under field conditions must be tried to determine if the wastes can be biologically or chemically degraded and the non-degradable components sufficiently tied up in the soil. Field tests should be run for each waste type. A test plot is a requirement in Ontario under the regulations of the Ministry of the Environment. If the test plot is successful then there should be minimal accumulation on the soil surface and maximal removal of contaminants before infiltration to the water table. If small amounts of contaminants do reach the water table the high attenuation capabilities of the soil, matrix diffusion in fracture zone and very slow, diffusion controlled flow in the underlying unfractured soils should minimize the potential for contamination of adjacent surface or underlying ground water resources. These processes are discussed in section 3.3.

OWMC's treated waste residues, as both liquids for irrigation and sludges for landfarming, are expected to be mainly inorganic. These are not biodegradable and therefore can not be considered as potential wastes for disposal via land treatment. Neither can the inorganic, non-biodegradable untreated wastes such as anion complexes and heavy metal sludges. The wastes which may have potential are select wastes from the OWMC categories of organic sludges and still bottoms (01), oils and greases (03), oil/water mixtures (04), organic and oily residues (05) and paint and organic residuals (08). These categories make up less than 25% of the total untreated waste. The actual quantities of untreated wastes that may have potential for land treatment are likely considerably less.

From a hydrogeologic viewpoint the following conclusions can be made about land treatment on low permeability soils.

(1) For specific waste streams land treatment is a viable disposal option that should not pose concerns to surface water or ground water resources.

(2) To minimize the potential for surface or ground water affects the site and waste to be disposed must be chosen through experimental application test plots and run-off and application rates controlled during operation.

(3) The specific waste streams that have potential for land treatment are the highly biodegradable fractions of the untreated wastes. These are estimated to be less than 25% of the total waste being accepted by OWMC. Therefore land treatment is a partial disposal option only.

(4) The treated wastes and portions of the untreated wastes are inorganic and therefore can not be disposed of by land treatment.

(5) Land treatment operations in Ontario are restricted by cold weather, snow and wet weather to about 100 to 120 days of application. Storage facilities are required at other times of the year.

Based on these conclusions we make the following recommendations for stage 2 studies;

(1) that the viability and value of land treatment as a disposal option for the biodegradable fraction of the untreated wastes be assessed with respect to other treatment alternatives, such as incineration.

(2) Should land treatment be chosen as a disposal option, potential waste streams should be identified and test plot experiments initiated.

5.0 MINE
DISPOSAL

5.1 INTRODUCTION

This evaluation is for southern Ontario only (i.e. south of the 46th parallel). The mines of southern Ontario occur in a broad geologic setting including both the crystalline rocks of the Precambrian Shield and layered Paleozoic sedimentary rocks. Each of these geologic settings represents distinctly different hydrogeologic environments. In the following sections the general geology and hydrogeology of these settings is briefly described. Only existing mines in these settings are considered. The largest active and inactive mines are described since their size makes them the most likely candidates for potential disposal repositories. The feasibility of these mines and their favourable/unfavourable characteristics are evaluated from a hydrogeologic and preliminary geotechnical aspects for both untreated and treated waste residual disposal.

5.2 PRECAMBRIAN GEOLOGY OF SOUTHERN ONTARIO

Precambrian rocks are exposed in the eastern portion of southern Ontario and form part of the Grenville Province (Figure 11). The Grenville Province is one of seven major structural divisions that form the Precambrian Shield in Canada. In Ontario it occurs from just south of Sudbury in the north to Lake Simcoe in the south. It is bounded by Georgian Bay in the west and extends eastward across southern Quebec and Labrador.

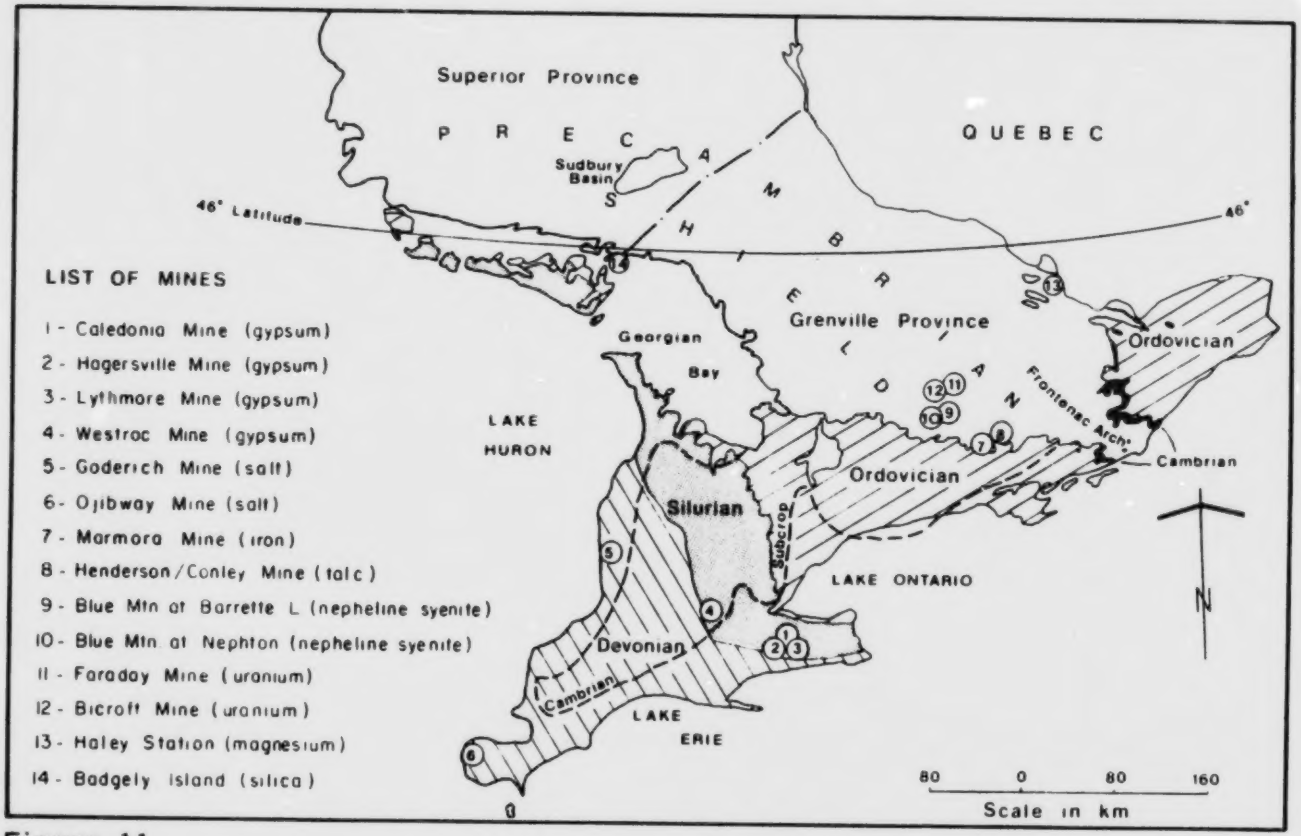

Superior Province
P R E C A M B R I A N
Sudbury Basin
S H I E L D
QUEBEC
46° Latitude
46°
Georgian Bay
Grenville Province
LAKE HURON
Frontenac Arch
Ordovician
Cambrian
Ordovician
Silurian
Subcrop
LAKE ONTARIO
Devonian
Cambrian
LAKE ERIE
N
80 0 80 160
Scale in km
LIST OF MINES
1 - Caledonia Mine (gypsum)
2 - Hagersville Mine (gypsum)
3 - Lythmore Mine (gypsum)
4 - Westroc Mine (gypsum)
5 - Goderich Mine (salt)
6 - Ojibway Mine (salt)
7 - Marmora Mine (iron)
8 - Henderson/Conley Mine (talc)
9 - Blue Mtn at Barrette L (nepheline syenite)
10 - Blue Mtn at Nephton (nepheline syenite)
11 - Faraday Mine (uranium)
12 - Bicroft Mine (uranium)
13 - Haley Station (magnesium)
14 - Badgely Island (silica)

Figure 11

Bedrock Geology Of Southern Ontario & Mine Locations (Geology Modified From Hewitt, 1971)

The rock types found within the Grenville Province are quite varied and represent many different ages within the Precambrian Era. However, all rock types within the Grenville Province appear to have undergone the same geologic events about 950+/- 150 million years ago known as the Grenville Orogeny. During this time ancient sedimentary rocks became highly deformed and were intruded by igneous rocks causing complex folding of the sedimentary layers and recrystallization of rocks under high temperatures and pressures. This resulted in a complex sequence of deformed metasedimentary rocks and igneous intrusive rocks. Consequently, the geology maps of this area show a complex intermixing of rock types.

Exposures of the Precambrian bedrock in eastern parts of southern Ontario are due to a regional bedrock structure known as the Frontenac Arch (see Figure 11). This feature is a northwest-southeast trending ridge or broad upland area of Precambrian bedrock. This topographically high area has existed for millions of years resulting in the erosion of the bedrock surface rather than deposition as has occurred over the Michigan Basin to the west and the Appalachian Basin to the south and east. The Frontenac Arch appears to be a relic structural feature of the Precambrian Shield and is relatively stable.

Rocks of the Precambrian era are, in most cases, very hard due to the presence of silicate minerals and exhibit a crystalline nature. Their porosities are relatively low, less than 5%, and they are generally poor aquifers. Ground water is usually transmitted through joints or fractures in the rock. The quantity of water flowing through these rocks is quite small, however, the nature of the flow along fractures makes it possible for water to move rapidly and potentially over large distances.

Crystalline carbonate rocks, such as the dolomitic limestones and marbles of eastern Ontario, are much softer than most silicate rocks of the Precambrian Shield. The partially soluble nature of these rocks creates the potential for solution weathering at/or near the ground surface. This is evident in many areas of eastern Ontario where these rock types outcrop. Their hydraulic conductivity may be significantly higher than most silicate rocks, particularly where jointing and fracturing is abundant. It has been found that joints and fractures may occur to depths of several kilometres, however, they occur less frequently, are often very tight or closed by mineral precipitates and may not be interconnected to surface.

5.2.1 MINING ACTIVITIES

Characteristic of the Grenville Province in the eastern portion of southern Ontario is the abundance of deformed crystalline carbonate and volcanic rocks. The deformation, recrystallization and subsequent igneous intrusions and structural faulting of these rock types have resulted in numerous mineral occurrences. Mineral exploration activities have therefore concentrated in these areas and have resulted in literally hundreds of small scale mining operations over the past century. Many operations were confined to surface trenching of exposed ore and some were developed as shallow underground workings, generally less than 100 m deep. Details from many of these small mining operations are available from the Ontario Department of Mines (now Ontario Geological Survey) Industrial Mineral Reports and Circulars.

Relatively few mining operations have been developed to sufficient size to accommodate the waste volumes expected by OWMC (150,000 to 420,000 cubic m/a over a few decades). We have assumed that only the mines with sufficient production to prompt the construction of a mine plant and ore processing facilities are of sufficient size to accomodate the expected waste volumes. One underground mine and four open pit mines of sufficient size were listed as active in the Precambrian rocks of southern Ontario during 1982 by the Ontario Geological Survey. These are shown on Figure 11 and are summarized in Table 6.

A large number of mines and mining prospects have been abandoned over the years in the Precambrian rocks of eastern Ontario. Three of the largest abandoned or inactive mining operations are given in Table 7.

A mine plant and ore processing facilities were constructed at each of the above mines.

Numerous quarry operations for the extraction of limestone cement, aggregates, marble, peat and lapidary minerals (i.e. sodalite, rose quartz and beryl) were also reported. As outined in Section 1.5.5 these quarries are considered too shallow, too permeable and too close to aquifers for further consideration.

5.2.1.1 Underground mines

There is presently only one large, active, underground mine and two large abandoned or inactive underground mines in the Precambrian of southern Ontario which could potentially be considered for waste disposal. Each of these operations is briefly described below to provide a summary of information. More detailed data remains in our files and in the published literature.

The Henderson/Conley Talc mine is located in Huntingdon Township, 2 km east of the town of Madoc. Parts of this mine

TABLE 6: MAJOR ACTIVE PRECAMBRIAN MINES IN SOUTHERN ONTARIO, DURING 1982

NAME	TYPE	PRODUCT
Henderson/Conley Mine	underground	talc
Blue Mountain Mine (at Nephton)	quarry	nepheline syenite
Blue Mountain Mine (at Barrette Lake)	quarry	nepheline syenite
Haley Station Mine	quarry	dolomite (magnesium)
Badgely Island Mine (Georgian Bay)	quarry	silica

TABLE 7: MAJOR ABANDONED PRECAMBRIAN MINES IN SOUTHERN ONTARIO

NAME	TYPE	PRODUCT
Madawaska Mines Ltd. (Faraday Uranium Mine)	underground	uranium ore
Bicroft Mine	underground	uranium ore
Marmora	open pit	iron ore

complex have been active since 1896. Currently two shafts service several levels of the mine. Previous shafts have caved. The ore bodies lie within a banded dolomite to proven depths of 165 m. The excavated volume is not known due to the irregular development of the mine and caving of some of the workings. The mine water supply, as well as local water supplies are developed in the upper 20 to 30 m of either bedrock or glacial deposits. Ground water supplies are small, generally yielding less than 1.5 L/s.

The Faraday uranium mine is located in Faraday Township of Hastings County. The mine has operated over two periods; 1957 to 1963 and 1975 to 1982. The mine is currently inactive. Underground workings are accessed by two shafts to a maximum depth of 472 m. The ore body is associated with granite and pegmatite intruded through metavolcanic and metasedimentary rocks. Over 139 km of drill holes have been constructed to identify the ore body. Local water wells are completed in either overburden glacial deposits or bedrock to depths less than 50 m. Ground water supplies are generally less than 2 L/s. Little background hydrogeologic data are available in the mine area.

The Bicroft uranium mine is located in Cardiff Township, 3 km west of Cardiff in Haliburton County. The mine operated from 1956 to 1963. The thirteen underground working levels were accessed by two shafts, the deepest being 562 m. The ore body is associated with granitic and syenite pegmatite dikes that have intruded metasedimentary and metavolcanic rocks. Local ground water supply wells extend to depths of up to 30 m and are usually completed in bedrock. Yields of up to 8 L/s have been recorded, however, most yields are less than 1.5 L/s.

5.2.1.2 Open pit mines

There are five relatively large open pit mining operations in the Precambrian Shield south of the 46th parallel. Four of these are currently active. These mines are similar to large aggregate quarries and are only classified as mines based on the minerals extracted. The five open pit mines described below, are located on, or have been completed into, Precambrian rocks.

The Blue Mountain nepheline syenite mine at Nephton is located in Methuen Township of Peterborough County. The open pit mine has been in operation since 1935. The ore body outcrops and consists of a large irregularly shaped intrusive mass that measures approximately 2 by 4 km. The current mine is located on topographically high ground and the working is dry. This is likely a local recharge area. Only a few shallow wells occur in the area. The mine well is 17 m deep and has a yield of about 0.1 L/s.

The Blue Mountain nepheline syenite mine at Barrette Lake is located in Methuen Township of Peterborough County. The open pit mine is about 6 km from the Blue Mountain mine at Nephton and has been in operation since 1956. Three pits have been developed by this mine to shallow depths of about 9 m. The pits are relatively dry and are likely local recharge areas. The mine well yields 0.2 L/s from shallow bedrock. Other wells in the area have yields up to 0.4 L/s from depths of about 15 m.

The Marmora iron ore mine is located in Marmora Township of Hastings County and is about 2 km from the town of Marmora. The mine operated from 1952 to the mid 1970s. The magnetite rich ore body is developed in recrystallized carbonate host rocks. Approximately 35 m of Paleozoic rocks overlie the ore deposit.

These have been removed at the mine site. The open pit is about 800 m long by 400 m wide and is about 150 m deep. The mine is partially filled with water. Dewatering was required during mining operations. Currently the mine water level is kept below the regional water table by order of the Ontario Ministry of the Environment. This order is in effect to protect local domestic wells from contamination.

The Haley Station magnesium mine is located in Ross Township of Renfrew County some 35 km southeast of Pembroke. The mine has been operated by various companies since the early 1940s. Two pits have been developed to depths of about 30 m. The ore body consists of Precambrian metasedimentary dolomites. Most of the mining activity is above the water table. The mine water supply is serviced by two wells to depths of 53 and 96 m in the dolomitic rocks. Both wells have yields of less than 1 L/s. Most wells in the area are located in the bedrock.

The Badgely Island silica mine is located on Badgely Island off the north shore of Georgian Bay some 26 km east of Little Current. The mine has been in operation since 1971. The pit has been developed within the orthoquartzite of the Bar River Formation for the production of high quality silica. There is very little hydrogeologic information known at the mine site. The pit is likely above the regional water table.

5.2.2 HYDROGEOLOGIC SUITABILITY OF PRECAMBRIAN MINES FOR WASTE DISPOSAL

Underground mines in the Precambrian Shield rocks of southern Ontario are within complex geologic environments. The metamorphic and intrusive history of the Precambrian rocks has created joints, faults and fractures which can act as major conduits for ground water flow and contaminant migration. The complex subsurface relationship of the rock types make it difficult to determine the ground water flow systems. Therefore this environment provides a high level of uncertainty in being able to predict contaminant migration. The complexity of the system also makes it difficult to monitor for contaminants and implement remedial measures, if required.

Some underground workings are in excess of 500 m in depth, however, most are irregular in nature and often occur on several levels with the uppermost levels relatively close to surface and local aquifers. The underground mines and surficial quarries would require some measure of dewatering throughout any disposal operation. In some cases mine stability is poor, requiring shoring to prevent caving of the excavations.

The following comments can be made regarding the unsuitability for waste disposal in the mines and quarries investigated;

(1) The Henderson/Conley talc mine has complex geology and somewhat unstable underground workings. Old caved mine shafts may act as additional pathways for contaminant movement, especially to overlying aquifers.

(2) The Faraday uranium mine has complex geology. Numerous unmarked exploration holes provide additional pathways for contaminant movement, especially to overlying aquifers.

(3) The Bicroft uranium mine has complex geology, irregular workings due to an irregular occurrence of the ore body, and major dewatering problems.

(4) Both Blue Mountain nepheline syenite quarries have complex geology and are located in ground water recharge zones.

(5) The Marmora iron ore open pit mine has major dewatering problems, intersects local aquifers and is in close proximity to local water wells.

(6) The Haley Station magnesium open pit mine has complex lithology and structure, with local water well supplies in the same rocks.

(7) The Badgely Island silica open pit mine has a complex geology and is in close proximity to Georgian Bay.

Based on the above discussion the general factors which do not favour the utilization of Precambrian underground mines for waste disposal are summarized as follows:

(1) complex subsurface geology offers a low level of predictability for contaminant movement,

(2) underground mine operations extend into shallow ground water flow systems increasing the risk of contamination of shallow aquifers,

(3) deeper levels of mine operations are difficult and expensive to monitor from surface,

(4) remedial measures following contaminant migration would be difficult,

(5) dewatering is a perpetual operational requirement,

(6) extensive exploration drilling has resulted in many unmarked boreholes that may act as additional conduits for contaminant migration,

(7) Precambrian rocks in general have poor chemical attenuation characteristics,

(8) safety problems related to structural stability with underground workings,

(9) some underground excavations are irregular and therefore not geometrically well suited to waste placement,

(10) potentially low porosities and high permeabilities in a fractured rock terrain means that contaminants can migrate over large distances in a short time.

The following factors favour the use of underground Precambrian mines for waste disposal:

(1) the deeper levels of the inactive uranium mines are well removed from shallow ground water aquifers,

(2) there are relatively few water supply wells near the mine sites minimizing the number of people exposed to potential ground water contamination risks.

From a hydrogeologic viewpoint open pit mines are poorly suited for waste disposal for the following reasons:

(1) shallow depth of excavation with close proximity to shallow water supply aquifers increases potential for ground water contamination,

(2) fractured and jointed quarry walls provide a low level of natural containment of leachate,

(3) complex geology of host rock provides a low level of predictability for contaminant movement,

(4) mitigative measures are difficult due to fracture permeability and complex geology of host rocks,

(5) deeper excavations require dewatering, and quarries developed on higher ground are likely ground water recharge zones.

In summary, it is concluded that the alternative of disposal into existing mined space in Precambrian rocks of southern Ontario does not, at this time, appear to be a preferred disposal alternative for either treated or untreated wastes.

5.3 PALEOZOIC GEOLOGY OF SOUTHERN ONTARIO

Paleozoic formations underlie most of southern Ontario south of a line from the southern Georgian Bay - Lake Simcoe area eastward to Kingston, as well as much of the area between the St. Lawrence and Ottawa Rivers east of Brockville (Figure 11). These bedrock formations dip gently to the west and south beneath the Great Lakes into Michigan, Ohio, Pennsylvania and New York States forming parts of the Michigan and Appalachian Basins (Figures 12 and 13). Accumulations of up to 4300 m of

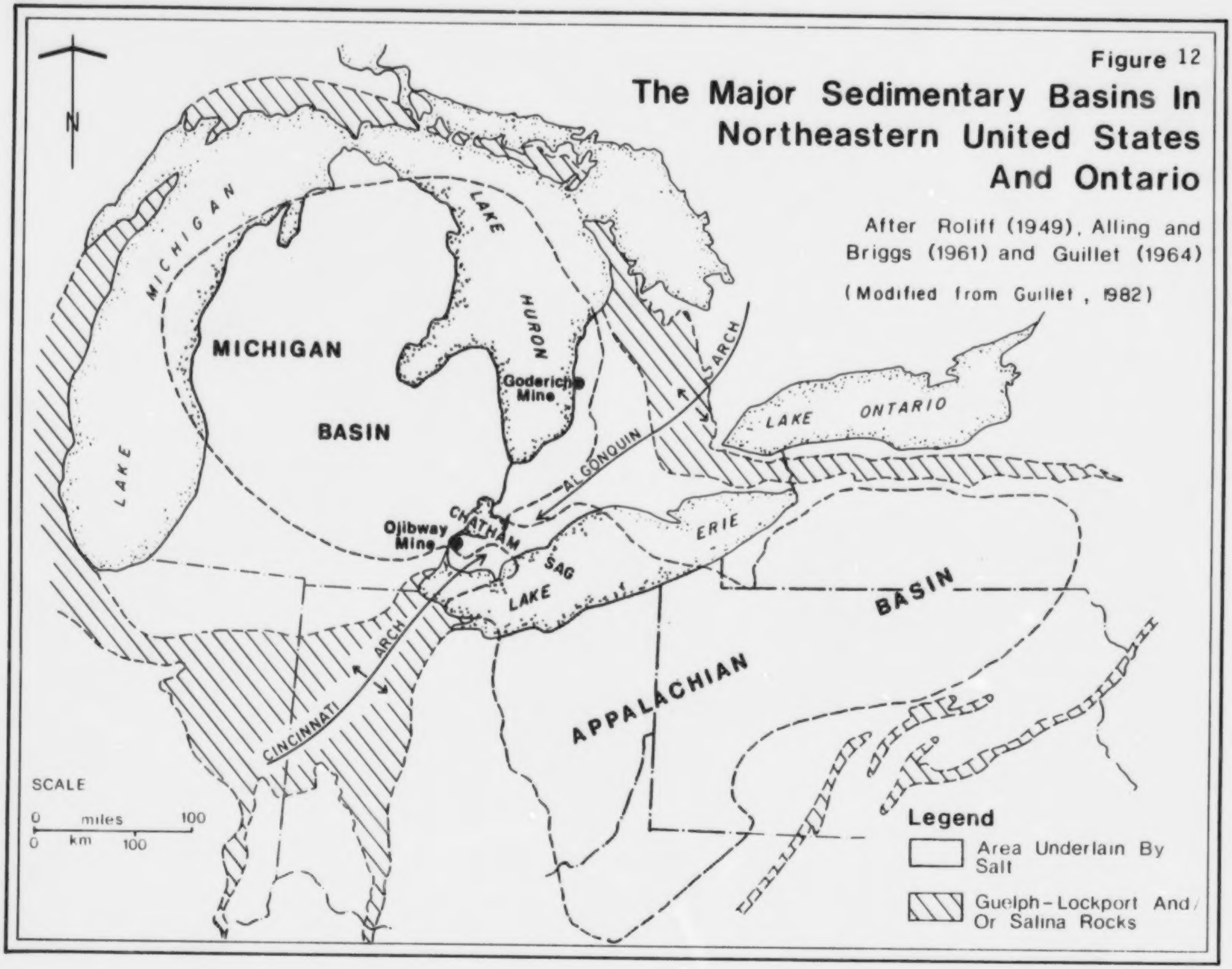


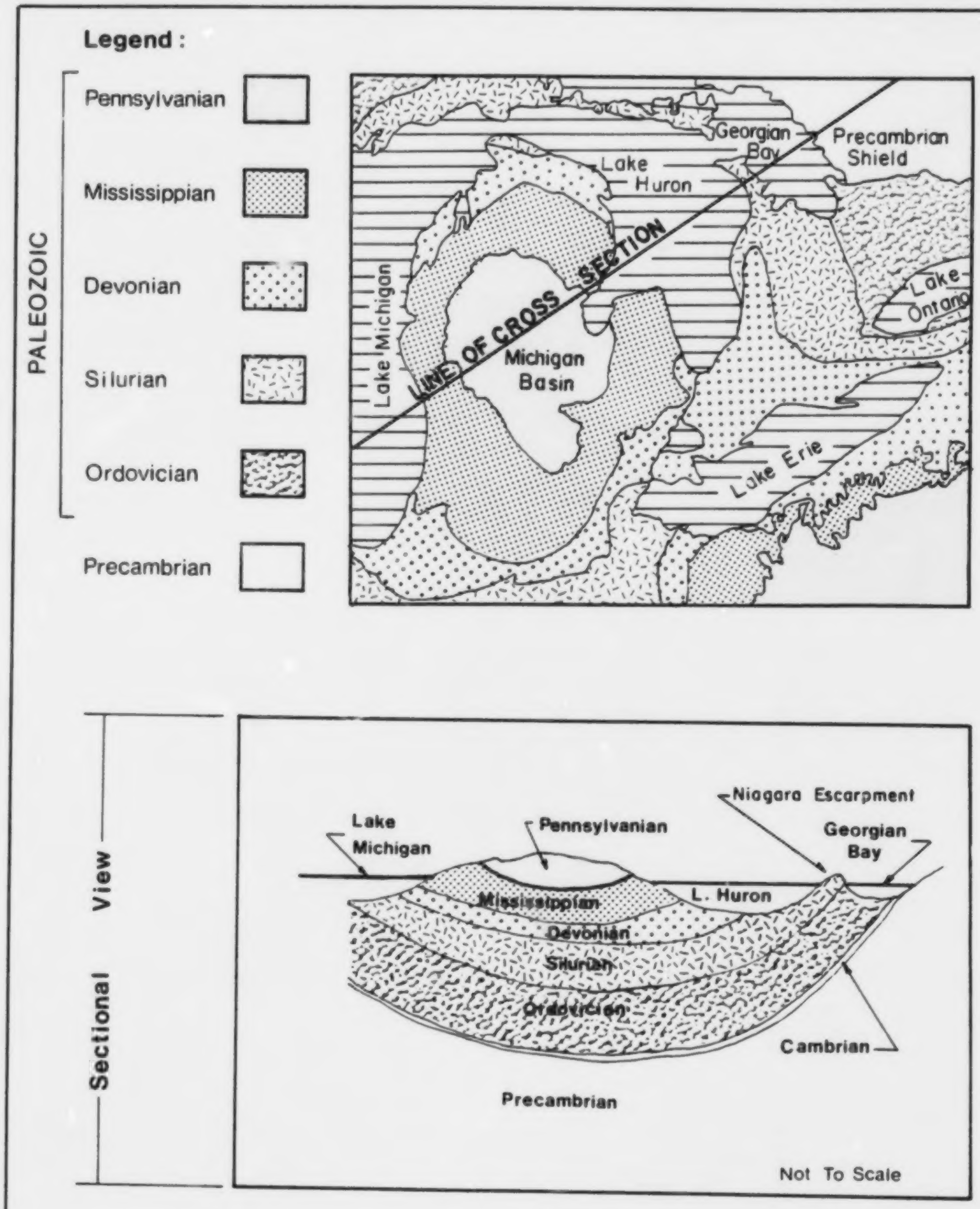
Figure 12

The Major Sedimentary Basins In Northeastern United States And Ontario

After Roliff (1949), Alling and Briggs (1961) and Guillet (1964)

(Modified from Guillet, 1982)

N
LAKE MICHIGAN
MICHIGAN
BASIN
LAKE HURON
Goderich Mine
Ojibway Mine
CHATHAM
SAG
LAKE ERIE
LAKE ONTARIO
ALGONQUIN
ARCH
CINCINNATI ARCH
APPALACHIAN
BASIN
SCALE
0 miles 100
0 km 100
Legend
Area Underlain By Salt
Guelph-Lockport And/Or Salina Rocks


Legend:
PALEOZOIC
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Precambrian
Georgian Bay
Precambrian Shield
Lake Huron
Lake Michigan
LINE OF CROSS SECTION
Michigan Basin
Lake Ontario
Lake Erie
Sectional View
Niagara Escarpment
Lake Michigan
Pennsylvanian
Georgian Bay
L. Huron
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
Not To Scale

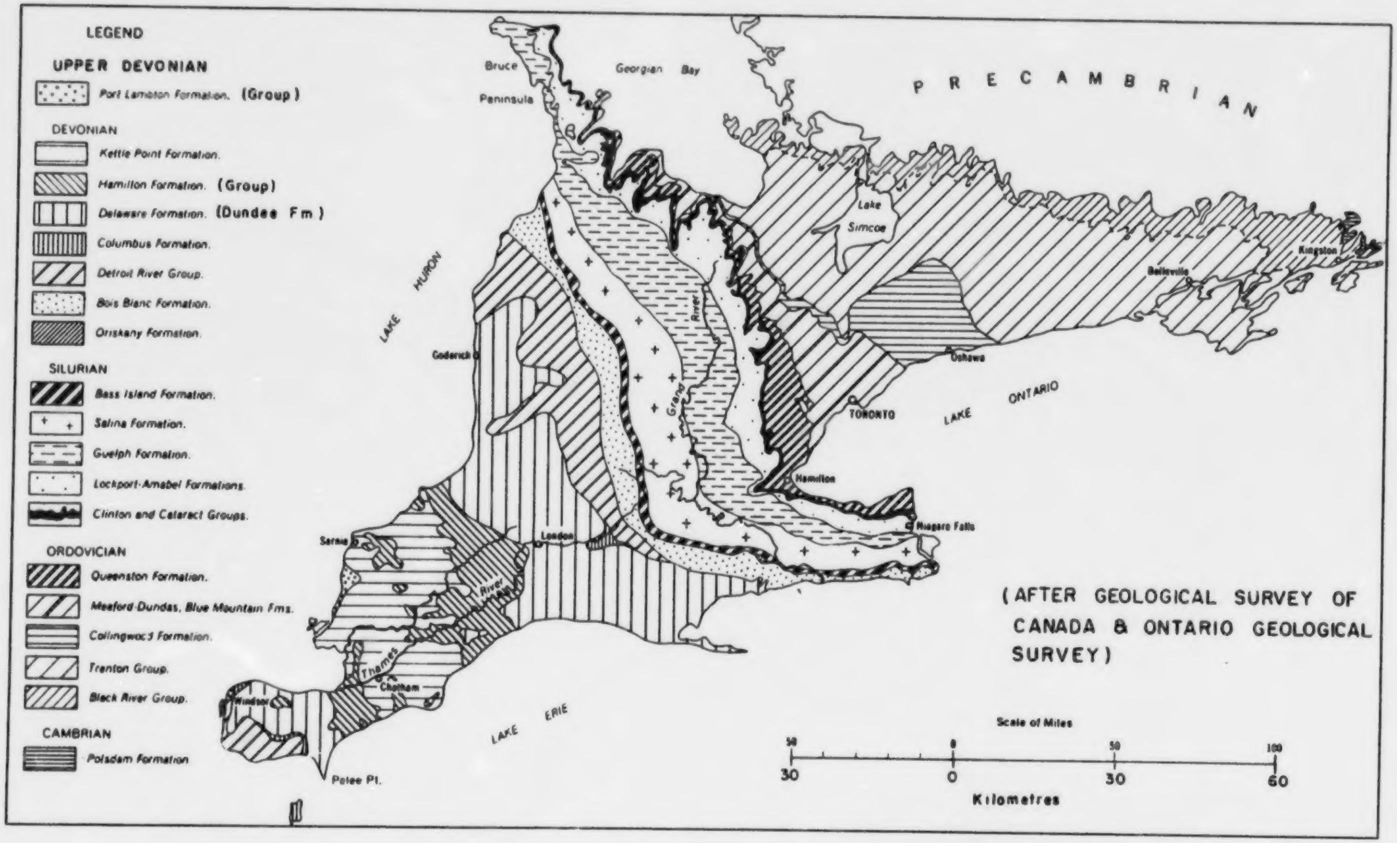
Generalized Map and Cross Sectional Sketch of the Michigan Basin

FIGURE 13

Gartner
Lee
Associates
Limited

sedimentary rocks occur in the Michigan and Appalachian Basins in the U.S.A. Within southern Ontario the Paleozoic rocks are represented by bedrock formations of the Cambrian, Ordovician, Silurian and Devonian age up to 1500 m in thickness (Figure 14).

The Paleozoic formations of southern Ontario lie beneath a cover of glacial deposits and are occasionally exposed along the Niagara Escarpment, river beds or in areas of very thin surficial cover. These formations are generally well layered and can be traced in subsurface borings as continuous over large distances. Their composition is primarily carbonate consisting of dolomites, limestones and shales although some evaporite and sandstone beds are present. These rock types are often interbedded and vary in their physical and chemical characteristics. The limestones and dolomites exhibit a range of textures from very fine grained to coarsely crystalline to massive fossiliferous structures. These rock types are often well layered, fractured or porous and are excellent aquifers. The shales may occur as very thin laminae within carbonate or evaporite beds or as very thick accumulations with occasional silty hard bands such as those of the upper Ordovician Period. These rock types are generally very dense with very low permeabilities and are poor aquifers. Evaporite beds of gypsum, anhydrite and salt are found within the upper Silurian Salina Formation. These beds sometimes occur with dolomite or shaly dolomite beds and where they are at shallow depth they are susceptible to dissolution by ground water percolation. The evaporite beds are not aquifers due to their very low permeabilities. However, where evaporite deposits are interlayered with other rock types and where dissolution has occurred, permeabilities may become higher. These are not, however, concerns for evaporite deposits that occur at depth.


LEGEND
UPPER DEVONIAN
Port Lambton Formation. (Group)
DEVONIAN
Kettle Point Formation.
Hamilton Formation. (Group)
Delaware Formation. (Dundee Fm)
Columbus Formation.
Detroit River Group.
Bois Blanc Formation.
Oriskany Formation.
SILURIAN
Bass Island Formation.
Salina Formation.
Guelph Formation.
Lockport-Amabel Formations.
Clinton and Cataract Groups.
ORDOVICIAN
Queenston Formation.
Meaford-Dundas, Blue Mountain Fms.
Collingwood Formation.
Trenton Group.
Black River Group.
CAMBRIAN
Potsdam Formation
Bruce Peninsula
Georgian Bay
PRECAMBRIAN
Lake Simcoe
Kingston
Belleville
LAKE HURON
Goderich
Grand River
Oshawa
TORONTO
LAKE ONTARIO
Hamilton
Niagara Falls
Sarnia
London
River
Thames
Chatham
Windsor
LAKE ERIE
Pelee Pt.
Scale of Miles
30
0
30
60
Kilometres
50
0
50
100

(AFTER GEOLOGICAL SURVEY OF CANADA & ONTARIO GEOLOGICAL SURVEY)

FIGURE 14 - REGIONAL GEOLOGY OF SOUTHWESTERN ONTARIO
(Modified from Guillet, 1982)

Salt deposits at depth are under large pressures resulting in a "self healing" property whereby any naturally or artifically induced fissures can close up by plastic flow of the salt. This has been known to occur in boreholes that have penetrated thick salt beds. The distribution of salt beds is confined to southwestern Ontario (Figure 15) but also extend west and south into the United States.

Recent work by the Geological Survey of Canada (Sanford, pers. comm.) has shown that the southern Ontario craton underlying the paleozoic deposits formed into two blocks; the Bruce Block and the Niagara Block. The block boundaries are determined from deep geophysical work and seismicity. The Bruce Block is the most stable and has the lowest number of seismic events.

5.3.1 MINING ACTIVITY

The Paleozoic rocks of southern Ontario have provided a readily available source of construction aggregate for the building industry. Including lime for the cement industry, shale for the manufacture of brick, and to a lesser extent as a source of building stone. Numerous quarries have been developed throughout southern Ontario for the extraction of rock from various Paleozoic formations. Several of these operations are large and have processed over 1E+06 t/a.

As outlined in the study assumptions (Sections 1.5.5), Paleozoic pits and quarries are omitted for waste disposal consideration based on hydrogeologic factors. In general these deposits have high permeability, are directly connected to local aquifers and contaminant movement would be relatively unpredictable because ground water circulation is fracture controlled.

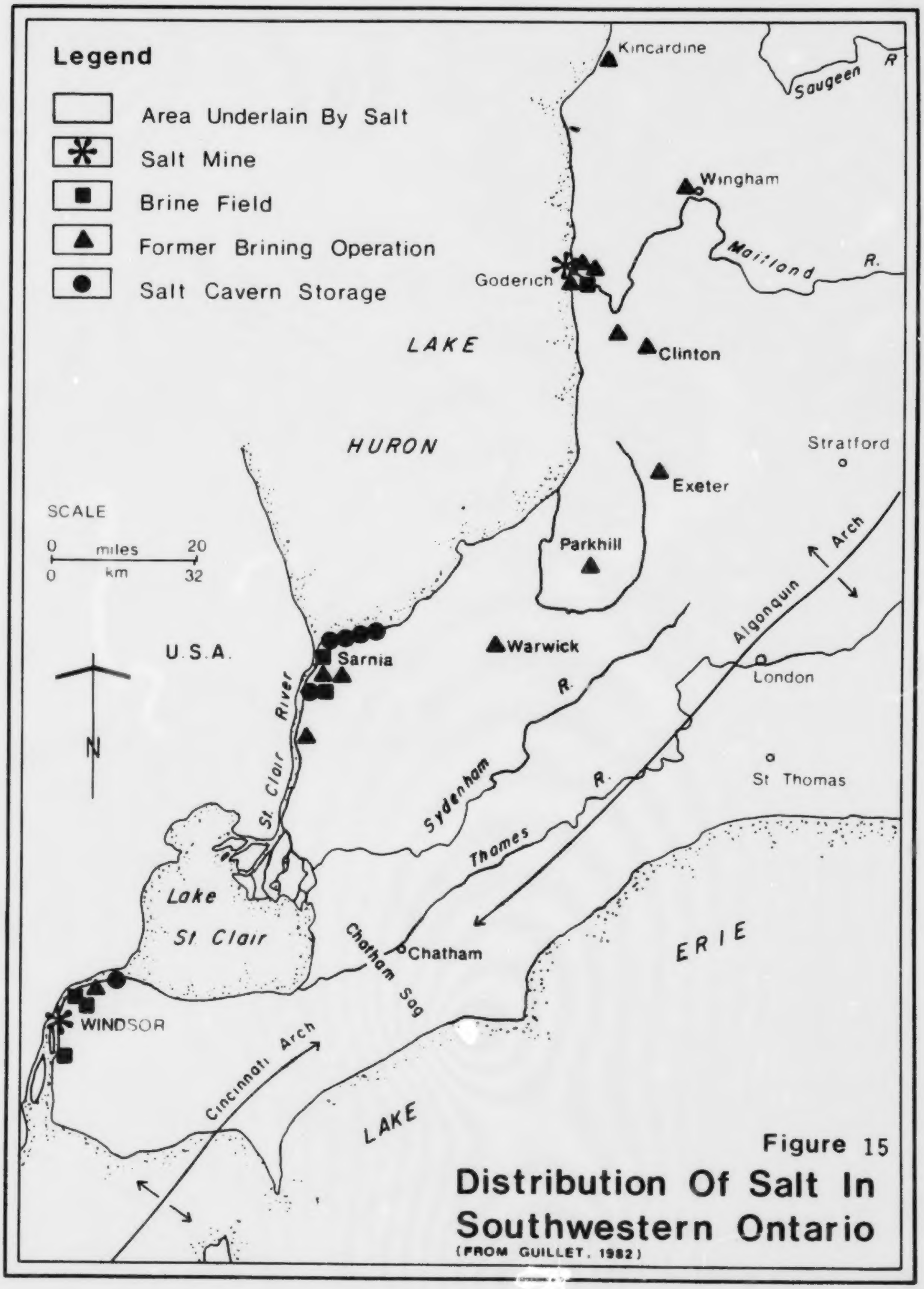

Legend
Area Underlain By Salt
Salt Mine
Brine Field
Former Brining Operation
Salt Cavern Storage
Kincardine
Saugeen R
Wingham
Maitland R.
Goderich
Clinton
LAKE
HURON
Stratford
Exeter
Parkhill
SCALE
0 miles 20
0 km 32
Algonquin Arch
Warwick
U.S.A.
Sarnia
London
St. Clair River
R.
N
St Thomas
Sydenham
R.
Thames
Lake
St Clair
Chatham
Chatham Sag
ERIE
WINDSOR
Cincinnati Arch
LAKE

Figure 15

Distribution Of Salt In Southwestern Ontario

(FROM GUILLET, 1982)

Underground mining activity has been concentrated in the evaporite deposits of the upper Silurian Salina Formation. The earliest underground mines were developed in the late 1800s in Brant and Haldimand Counties. These mines exploited the shallow gypsum seams that underlie the areas adjacent to the Grand River. Most of these were small, underground operations and were not long lived. Thirteen of these abandoned gypsum mines have been documented by Guillet, (1964 and 1983). Currently there are three operating underground gypsum mines in southern Ontario and their location together with those of the abandoned mines are shown on Figure 16.

The Salina Formation has also been exploited for its salt deposits that occur at depth in the southwestern portion of the province. The subsurface distribution of salt in southern Ontario is shown on Figure 15 and the stratigraphic position of the salt beds (evaporites) is shown on Figure 17. The total thickness of the Salina Formation is about 185 m at Windsor and about 350 m at Goderich. The salt thickness also increases from about 46 m at Windsor to 91 m in the Sarnia-Goderich area. Salt was first discovered in Ontario in 1866 while drilling for oil at Goderich. The hole was easily converted to a well for the pumping of salt brine and the Goderich Salt Company thus was formed. A number of other salt brine operations soon sprang up and by 1914 eleven companies were producing salt by brine well operations. As discussed in Section 1.5.5 this study does not evaluate the caverns formed by brining operations. Underground mining of salt began in the mid 1950s at Windsor and Goderich. These two mines have been in continuous operation since their opening and are currently the only two active underground salt mines in southern Ontario.

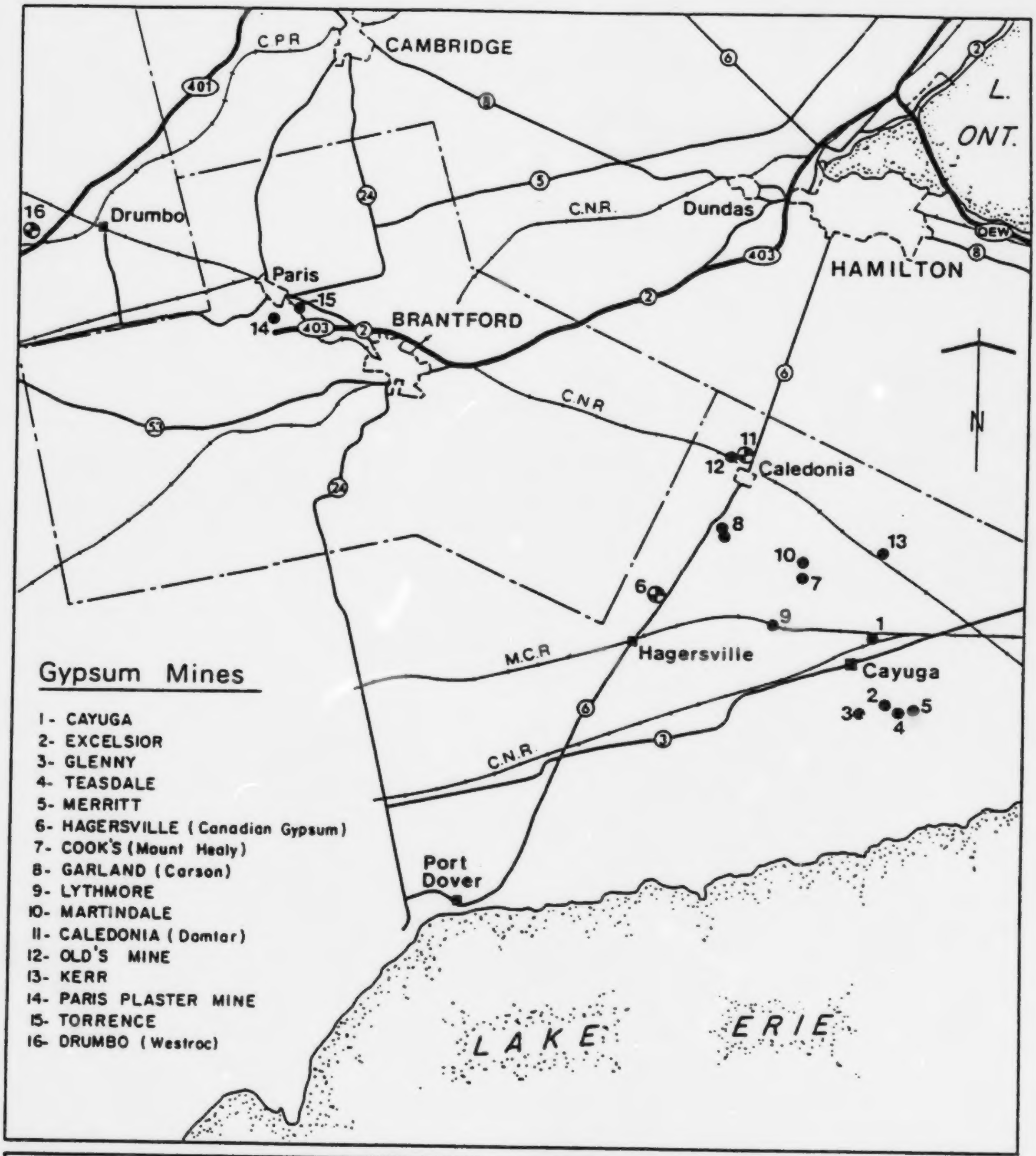

CAMBRIDGE
C.P.R.
401
6
8
L. ONT.
2
24
5
C.N.R.
Dundas
16
Drumbo
QEW
8
403
HAMILTON
Paris
15
2
14
403
2
BRANTFORD
6
C.N.R.
53
11
12
Caledonia
N
24
8
10
13
7
6
9
1
M.C.R.
Hagersville
Cayuga
2
3
4
5
6
3
C.N.R.
Port Dover
LAKE ERIE
Gypsum Mines
1- CAYUGA
2- EXCELSIOR
3- GLENNY
4- TEASDALE
5- MERRITT
6- HAGERSVILLE (Canadian Gypsum)
7- COOK'S (Mount Healy)
8- GARLAND (Carson)
9- LYTHMORE
10- MARTINDALE
11- CALEDONIA (Domtar)
12- OLD'S MINE
13- KERR
14- PARIS PLASTER MINE
15- TORRENCE
16- DRUMBO (Westroc)

Figure 16

Gypsum Mines Past & Present

Legend

◉	ACTIVE MINE
•	ABANDONED MINE

(From Guillet, 1983)

Scale

-5 0 10

km

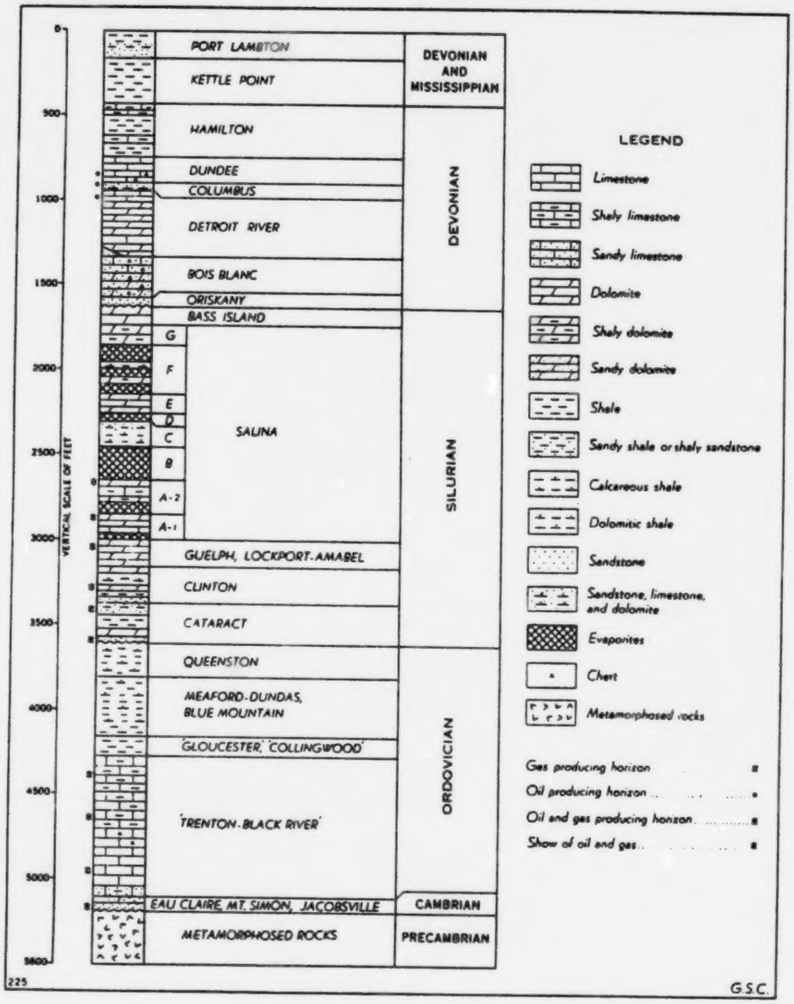

0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
VERTICAL SCALE OF FEET
PORT LAMBTON
KETTLE POINT
DEVONIAN AND MISSISSIPPIAN
HAMILTON
DUNDEE
COLUMBUS
DETROIT RIVER
BOIS BLANC
ORISKANY
DEVONIAN
BASS ISLAND
G
F
E
D
C
B
A-2
A-1
SALINA
SILURIAN
GUELPH, LOCKPORT-AMABEL
CLINTON
CATARACT
QUEENSTON
MEAFORD-DUNDAS, BLUE MOUNTAIN
'GLOUCESTER', 'COLLINGWOOD'
'TRENTON-BLACK RIVER'
ORDOVICIAN
EAU CLAIRE, MT. SIMON, JACOBSVILLE
CAMBRIAN
METAMORPHOSED ROCKS
PRECAMBRIAN
LEGEND
Limestone
Shaly limestone
Sandy limestone
Dolomite
Shaly dolomite
Sandy dolomite
Shale
Sandy shale or shaly sandstone
Calcareous shale
Dolomitic shale
Sandstone
Sandstone, limestone, and dolomite
Evaporites
Chert
Metamorphosed rocks
Gas producing horizon
Oil producing horizon
Oil and gas producing horizon
Show of oil and gas
225
G.S.C.

FIGURE 17- GENERALIZED GEOLOGICAL SECTION
FOR SOUTHWESTERN ONTARIO
(After Geological Survey of Canada)

(From Guillet, 1982)

In the following sections the three operating gypsum mines and the two salt mines are described and then discussed with respect to the possibility of waste disposal. In addition, one of the largest abandoned gypsum mine at Lythmore is discussed. The remaining abandoned gypsum mines are not evaluated mainly due to their relatively small size but also because of the lack of available information on these previous mining operations.

5.3.2 UNDERGROUND MINING

The two active underground salt mines in southern Ontario are located in the southwest part of the province at Windsor and at Goderich. These mining operations have been well documented by Hewitt (1962) and Guillet (1982). The development of gypsum mines in southern Ontario has been confined to the area of subcrop of the Salina Formation. They are developed mainly in the counties of Haldimand and Brant. The gypsum industry in Ontario is described in detail by Guillet (1964, 1983) and Cole (1930). The following paragraphs summarize the geology and hydrogeology of these mines.

5.3.2.1 Salt mines:

The Ojibway Salt mine is located adjacent to the Detroit River and is within the City of Windsor (see Figure 15). Underground operations are accessed by two vertical shafts 330 m deep and the main working level is within the uppermost salt unit of the Salina Formation (F Units) at 289 to 305 m. The salt bed is about 7.1 m thick and 5.4 to 6.3 m are being mined. The mining operations are by room and pillar methods and extend westward beneath the Detroit River to the International Boundary. The estimated open space within the mine as of 1982 was 1E+08 cubic m which was being added to at a rate of about 800,000 cubic m/a (Guillet, 1982).

The mine is dry and no dewatering is required. However, large flows of water were encountered in overlying rocks during sinking of the shaft in 1952. Artesian flows up to 90 L/s at a depth of about 64 m were measured. Aquifers as deep as 216 m were tested and found to be capable of yields as high as 50 L/s.

Most water wells in the area obtain water from shallow bedrock and are almost all less than 60 m in depth. The water quality is often sulphurous and yields are generally less than 2 L/s. Several wells have been tested with yields up to 8 L/s. The shallow overburden deposits consist mainly of clay with occasional sand layers and a few wells in the vicinity of the Ojibway Mine obtain their water supply from this material.

There do not appear to be any oil and gas fields within 20 km of the Ojibway Mine, although the A-1 and A-2 beds of the Salina Formation are known to contain oil and gas in other areas. The A-1 and A-2 beds are stratigraphically below the level of the Ojibway mine. Deep drilling activity has been confined to salt brining operations and for petroleum products storage. The latter use has also been made of the Salina Formation with the creation of solution cavities within the salt beds. Many of these brining wells are located within the City of Windsor. In addition, local salt brining operations for the production of salt are currently taking place at Windsor and Amherstberg, also from the lower salt beds of the Salina Formation. Existing information indicates a vertical stratigraphic separation of over 100 m between the underground mining operations at the Ojibway mine and the current salt brining and petroleum storage activities within the area. The closest petroleum storage wells are within 2 km of the Ojibway Mine. At one location the development of a sink hole at surface can be attributed to the location of a brining well.

Thus these wells can cause underground stability problems if poorly controlled.

The Goderich Salt mine is located within the Town of Goderich at the mouth of the Maitland River and on the shores of Lake Huron (see Figure 15). The underground operations are accessed by three vertical shafts that extend to 528 m depth. The second lowest salt bed (A-2 Unit) of the Salina Formation is being mined at a depth of about 537 m. This unit is about 25 m thick at this location, however, only the lower 12 m are being mined at this time. Anhydrite rocks underlie the mine and overlie the deepest

The mining operation is by the conventional room and pillar method. Mine production in 1982 was approximately 2E+06 tonnes creating approximately 700,000 cubic m of open space that year. An estimated 220 ha had been worked as of 1982 (Guillet, 1982) with an extraction ratio of 38 percent. The total estimated open space in the mine in 1982 was 1E+07 cubic m. Salt reserves beneath Lake Huron extending for about 5 km along the shore and 2 km into the lake are secured by 21 year renewable leases from the Ontario Government (Guillet, 1982).

The mining operations are dry and no dewatering is required. Large flows of ground water were encountered in the upper 107 m of the overlying Detroit River Dolomite during shaft sinking. Another high yield aquifer was encountered at a depth of about 244 m, near the top of the Salina Formation but some 280 m above the mine. Water flows within these aquifers were as high as 750 L/s with pressures as high as 2000 kPa. These zones were effectively sealed off with chemical grout and cement as the shaft was advanced.

The surficial deposits in the area are up to 50 m thick and overlie rocks of the middle Devonian Dundee Formation. Most water wells within the Goderich area are less than 60 m deep. The fine grained limestones of the Dundee Formation appear to be a major source of water for domestic wells in the area. Well yields are generally less than 1.5 L/s. A deep water supply well completed by Sifto Salt Company Limited to about 110 m was tested at 150 L/s, however, little information is available on this well test. Shallow granular deposits occur in the overburden deposits near surface in some locations and it appears that the Town of Goderich has three municipal wells completed into a shallow gravel aquifer.

There are no oil and/or gas fields in the immediate vicinity of the Goderich Salt mine although two small gas fields are located about 20 km away in Goderich and West Wawanosh Townships. Production from these fields is from formations of Silurian age and are known as the Bayfield and Dungannon gas fields respectively. There has been little activity associated with oil and gas exploration in the Goderich area. Most deep wells are associated with brining operations. These operations are confined to salt beds higher than the mine (A-2) horizon. The most recently completed brine well reaches a depth of 488 m and is located about 3 km east of the main shaft to the mine.

5.3.2.2 Gypsum mines

The Caledonia gypsum mine is located in Haldimand County about 2 km north of the Town of Caledonia (see Figure 16). The mine has been in operation since 1905 in two adjacent workings. The mine depth is up to about 25 m below surface, the gypsum seam is about 4 m thick and is part of the Salina Formation. A conventional room and pillar operation is used and some roof bolting is required. Access is by an inclined shaft or ramp from surface. Dewatering is necessary at rates varying from 15 to 30 L/s. Local domestic supplies as well as the Town of Caledonia municipal supply are obtained from a bedrock aquifer at depths of up to 30 m and with yields up to 30 L/s.

The Hagersville gypsum mine is located about 8 km southwest of the Caledonia mine (see Figure 16). The mine has been in operation since 1931. The mined gypsum seam is about 1.2 m thick, varies in depth from about 18 to 30 m, and is part of the Salina Formation. The mining operation is by room and pillar method and roof bolting is necessary for overhead stability. Mine access is by one vertical shaft and two ventilation shafts. Local water supplies in the area of the Hagersville mine come from bedrock aquifers up to 30 m deep. Yields vary from about 1 to 4 L/s. The regional Guelph-Lockport aquifer underlies the mine. No information is currently available about dewatering from this mine.

The Drumbo gypsum mine is located about 10 km northeast of the Town of Woodstock in Oxford County (see Figure 16). First production began in 1978. The mined gypsum seam is 1.7 m thick and occurs at a depth of about 116 m. The mining operation is by room and pillar method with roof bolting at 1.5 m centres. The underground rooms are only 1.7 by 6 m in area. Pillars are 6 m square. Local water supplies are completed at depths of up to 60 m and most utilize the extensive overburden aquifers of this area. Little is known of the Paleozoic hydrogeology in this area. Most shallow aquifers have reported yields of less than 2 L/s, although locally they could exceed this figure. No published information is available about dewatering operations at this mine.

The Lythmore gypsum mine is located about 8 km southeast of the Hagersville mine in Oneida Township (see Figure 16). The mine operated from 1916 to 1932 at several levels ranging in depth from 22 to 42 m within the Salina Formation. Local water supplies come from bedrock at depths of up to 30 m. Yields are generally in the range 1 to 4 L/s.

5.3.3 HYDROGEOLOGIC SUITABILITY OF PALEOZOIC MINES FOR WASTE DISPOSAL

Underground mining activity in Paleozoic rocks of southern Ontario have been restricted to salt and gypsum operations within the Silurian Salina Formation. The two operating salt mines are deep and dry and the gypsum mines are shallow and require some dewatering. In the following subsections the hydrogeologic implications are discussed with regard to these two types of mines for waste disposal.

5.3.3.1 Hydrogeologic assessment of salt mines

The two underground salt mines in southern Ontario are deep (300-500 m) and in areas of continuous evaporite deposits. Therefore the mines are well removed from aquifers containing fresh ground water resources. Large yields of ground water do occur in the overlying Devonian strata, however, the mine excavations remain dry and do not require dewatering. This is because the overlying and underlying salt and anhydrite beds as well as the mine salt beds themselves act as barriers to ground water flow due to their low hydraulic conductivities. The fact that these salt beds have existed for millions of years is evidence that ground water has not penetrated the salt. Otherwise dissolution would have occurred. Thus, leachate production and the migration of leachate into surrounding ground water is not a significant concern for wastes disposed in salt mines. In this regard there does not appear to be any major hydrogeologic constraint to using either of the salt mines discussed above for disposal. The only area of concern might be the mine shafts as future conduits for ground water into the mine or contaminants out. However, mine shaft sealing procedures are presently being developed by the radioactive waste disposal industry that should minimize this concern. Some migration of contaminants, away from the mine by diffusion, may occur if wastes, especially untreated liquids were in contact with the walls of the mine. This could be prevented during operation of the mine for disposal. However, even if contaminants were in contact with the walls, in the absence of a significant ground water component, the diffusion process in salt is so slow that the rates of migration and the fluxes would be very small.

More significant in evaluating the suitability of the salt mines as a disposal alternative are (1) geotechnical concerns such as mine stability, (2) future intrusions by humans that could connect overlying ground waters directly with the salt beds around the mine, (3) restricted access to future mining of the salt as a geologic resource, and (4) inaccessibility to the wastes after closure for future processing if required.

Salt deposits are subject to plastic behaviour, i.e. the salt can flow to a certain degree. This is both advantageous, because it self heals any fissures that may have developed due to mining, and disadvantageous because 'salt creep' can result in some mine instability concerns. Should failure of all or part of the mine occur it would likely result in failure of overlying beds and an influx of ground water from overlying aquifers. This ground water could potentially mobilize contaminants whose potential impact would be uncertain due to the complexities caused by the mine failure. There is very little published information available on salt creep in the Ontario mines, however, the operational performance of these mines, which spans almost 30 years, indicates the mined openings are relatively stable but do require roof bolting. This would have to be confirmed by detailed mine specific testing.

Since salt is a resource, the potential exists for future exploratory drilling or brining operations to infringe on the disposal area. This would likely not occur during operations or post closure care but could be a concern for future generations. A hole penetrating through overlying aquifers into the salt could result in an inflow of ground water into the mine that could dissolve the salt and mobilize contaminants. Brining operations could unknowingly result in salt and contaminants from the mine being dissolved and mixed into the salt being recovered at surface. As well, brining operations could cause stability problems in the salt beds. For example, a sink hole at surface within 2 km of the Ojibway mine can be attributed to failure of a brining well cavern.

If mining or brining is restricted within a certain radius of the disposal mine then the salt within this area is lost as a recoverable resource.

Due to the mines depth after mine closure and sealing of the shaft, the wastes would be difficult and probably uneconomical to retrieve should additional processing technology become available.

The following is a summary of hydrogeologic, geologic and geotechnical factors that favour the use of underground salt mines for the storage and/or disposal of OWMC's wastes:

(1) the salt beds have low permeability and therefore offer a high degree of natural containment,

(2) the mining operations provide large volumes of stable and dry storage space,

(3) the salt beds are well isolated from freshwater aquifers,

(4) the depth of mining operations provides a large buffer zone to the biosphere,

(5) salt creep and mine instability is not recorded as a problem in Ontario salt mines, and some plastic flow is a positive feature as it heals induced fractures thus retaining the formation's integrity,

(6) high degree of predictability of bedrock structure,

(7) low permeability backfill and shaft sealing technology is well advanced,

(8) risk assessment computer models are available through radioactive waste disposal programs,

(9) low permeability strata are present above and below the mines in case of a failure,

(10) nuclear waste disposal programs in several countries have considered salt for potential repositories and thus a continuing expansion of the salt data base is available for assessment,

(11) during operation monitoring of the waste can be done by visual inspecton.

The following factors do not favour the use of salt mines for the disposal of OWMC's wastes:

(1) aquifers are present in the bedrock strata overlying the Salina Formation, and mining operations extend below major surface water bodies,

(2) mine stability may be a long term concern,

(3) if required, remedial measures are difficult to implement due to the depth and inaccessibility of the rocks surrounding the mine, after site closure,

(4) salt is soluble in unsaturated brines and fresh water should mine failure or future drilling or brining cause ground water to enter the mine,

(5) monitoring could be expensive to accomplish from surface after site closure,

(6) cavity mining of the salt beds for petroleum products storage or salt brining in the vicinity of underground mining can cause stability problems or intersect the mine,

(7) restrictions on mining or brining in the vicinity of the mine can result in a loss of salt as a recoverable resource in the restricted area.

From a geologic and hydrogeologic perspective the Goderich mine has some advantages over the Ojibway mine. These are;

(1) the mine is deeper and thus further removed from the biosphere,

(2) the production salt bed is better isolated from known fresh water quality aquifers,

(3) it is located in the Bruce Block and thus is seismically more stable,

(4) there are less brining and oil/gas development wells in the Goderich area.

In summary, existing salt mines in Ontario appear to have potential as waste repositories.

5.3.3.2 Hydrogeologic assessment of gypsum mines

The gypsum mines operate within the upper Silurian Salina Formation. The host rock consists of layered dolomites and shales or shaly dolomites which are interbedded with the gypsum deposits. These rock types are capable of transmitting low to moderate volumes of water. The shale beds usually act as aquitards and serve to limit the amount of ground water flow into the mined openings. Fractures within the host rock and the bedding planes of the layered formations tend to serve as primary flow paths for ground water and contaminants. Mining of the gypsum by blasting may contribute to fracturing of the more competent beds and could thereby increase the permeability of the confining rock.

The gypsum mines operate at relatively shallow depths, the deepest being the Drumbo Mine at about 117 m. As these mines are shallow it increases their susceptibility to ground water infiltration from the overlying materials and their hydraulic connection with local aquifers. Water well records have shown that the gypsum mines occur within or slightly below local bedrock aquifers, except for the Drumbo mine area where the main aquifer is within the overburden sediments.

The gypsum mines occur in areas that have undergone considerable oil and gas exploration and development. The Cambrian oil and gas pools of Gables and Innerkip are within a few kilometres of the Drumbo Mine and the Silurian gas field of Haldimand covers much of Haldimand County. The level of oil and gas activity has not been as intense as the southwestern part of the province, however, a number of existing production wells and abandoned exploration wells have been drilled in the vicinity of the gypsum mines. These wells could provide potential conduits for contaminant transport where there are failures of the casings or where they have been improperly plugged. Abandoned water supply wells offer the same potential for contaminant migration and are likely to be of more concern because of the potentially large number of wells close to the mine operations.

Gypsum extraction for the larger mining operations has been by conventional room and pillar methods similar to the salt mining operations. The mined openings vary in size and have been relatively stable although roof bolting is often required and has become standard practice in the Drumbo Mine. The Drumbo Mine is also the smallest of the mines. Ground water occurs within the Salina Formation gypsum deposits and dewatering is required in the mining operations. This would likely become a perpetual maintenance requirement if waste disposal were considered for these mines.

The following is a summary of positive factors for waste disposal in southern Ontario Paleozoic gypsum mines:

(1) relatively large mined openings,

(2) subsurface geology relatively uniform with moderate level of predictability,

(3) moderately easy to monitor due to relative shallow depth,

(4) relatively impermeable overburden to restrict amount of ground water infiltration with the exception of the Drumbo Mine,

(5) dewatering would create hydraulic gradients toward mine and prevent outward flow of potential contaminants.

The following factors are negative aspects of gypsum mines for waste disposal:

(1) mining operations are within or slightly below local bedrock aquifers,

(2) moderately low level of natural containment offered by host rocks,

(3) mitigative measures for waste containment would be moderate to difficult,

(4) perpetual dewatering may be required,

(5) the potential for major fracturing of the formation due to mine instability,

(6) ground water flow away from a mine after closure should dewatering be discontinued would likely be fracture controlled,

(7) perpetual maintenance required of shafts and access tunnels after mine closed for monitoring purposes,

(8) relatively shallow depth of operations provides short travel distance of contaminants to utilize aquifers and short response time for mitigative measures,

(9) abandoned water wells and oil and gas wells are potential conduits for contaminant migration.

In summary, based on hydrogeology, geology, and preliminary geotechnical information, the option of using existing gypsum mines in Ontario does not appear to be a preferred disposal alternative for OWMC.

5.4 EXPERIENCE IN MINE DISPOSAL ELSEWHERE

Mine disposal has not been commonly adopted world wide. There are no known commercial operations in North America. Several base metal mines backfill with some tailings. Two U.S. States have undertaken preliminary studies, most notably Minnesota, however, to date all projects appear to be on hold for non-technical reasons. More detail on these proposed mine disposal sites are given in the Geraghty & Miller, Inc. report (Volume 2). In Europe several mines have been used for waste storage and/or disposal. In Germany the Asse mine has been used for low and intermediate level radioactive waste and the Kali-Salz mine for special industrial wastes. Both England and Sweden are investigating the possibility of using underground mines for various types of radioactive waste. The Nyrex project in England is assessing the potential of an old salt mine for disposal of low and intermediate level radioactive wastes. In Sweden the Strippa mine is being investigated as a potential high level radioactive waste repository.

Although to date, mine disposal has not been commonly used, a substantial data base is available from the various radioactive waste management programs world wide. Most countries with radioactive waste (Canada, China, England, Germany, Finland, France, Italy,. Sweden, Switzerland, U.S.A.) have active programs to identify suitable underground repositories. Much of this work is directed towards granitic or salt deposits, although other rock types such as shale, clay and basalt are being considered. However, most countries are investigating the possibility of opening their own underground space rather than utilizing existing mines.

Along with the geologic/hydrogeologic data base referred to above, the radioactive waste management programs have expended considerable effort on other scientific studies related to waste isolation from the biosphere. Some of these studies which are relevant to this study for OWMC are: container design, container materials, container storage, waste compatibility, room and shaft sealing materials and risk assessment.

The most applicable operating mine disposal system for consideration in this report is that of the Kali-Salz mine in West Germany. This operation is well known and is described in the following paragraphs. The description is based on OWMC's European Tour report and information published by Kown et al (1977).

The Kali-Salz potash mine commenced operations in 1901 and extensive underground mining has occurred in the Herfa-Neurode area. A room and piller operation has been used since the introduction of trackless LHD equipment in 1969. The room widths are 12 to 14 m with roughly square pillars 3.6 to 4.3 m on each side. The height of the rooms are 2 to 3 m. The untreated waste storage area is located at a depth of about 700 m. Roof bolting with 1.2 m roof bolts on a 2 m pattern is carried out in areas of possible roof problems. The mine is overlain by a cover of rock salt about 170 m thick which forms a low permeability seal to the overlying sandstones. A 100 m thick layer of rock salt lies immediately below the waste storage level.

Untreated waste storage is confined to rooms with a minimum height of 2.3 m and conversion to storage includes renewed roof bolting and preparing the floor area by grading and compacting fine salt as a base. The waste is stored in either 208 L steel drums, smaller steel drums or plastic drums. Brick walls are constructed at prescribed intervals to isolate different types of waste which are not chemically compatible. Outdated drugs are put in an isolated fenced room under lock and key.

The mine is accessed by a vertical shaft which also provides fresh air to the underground storage and mining areas and another ventilation shaft is connected to the storage area by an isolated return air system. No water was observed in the mine or in the shafts. Water was encountered during shaft sinking in an overlying aquifer, however, this has been effectively sealed off with steel tubing. The mine areas do not show evidence of undue pillar stressing and appear to be stable.

5.5 CONCLUSIONS ON MINE DISPOSAL

The previous sections have discussed the geologic and hydrogeologic factors affecting the potential of using existing mines for waste disposal. Although mine disposal is not commonly used, it is not a new concept and is likely to become more widely accepted in the future.

In southern Ontario two geologic settings have existing mines for consideration: the Precambrian mines of the Canadian Shield and the Paleozoic mines located at the periphery of the Michigan and Appalachian sedimentary basins. The following conclusions are made based on our hydrogeologic, geologic and preliminary geotechnical evaluation:

(1) Ontario Provincial laws and guidelines encompassed under the Ministries of Environment, Labour and Natural Resources do not preclude mine disposal as an option.

(2) There are hydrogeologic constraints associated with the use of Precambrian mines as a disposal alternative for OWMC's wastes. These constraints are the uncertainties associated with ground water flow in fractured

rock, poor geologic and hydrogeologic predictability, poor natural containment, requirement for active systems and perpetual care, proximity to aquifers and difficulty for monitoring.

(3) There are hydrogeologic and geotechnical constraints associated with the use of Paleozoic gypsum mines as a disposal alternative for OWMC's wastes. These are the uncertainties associated with poor isolation from known shallow aquifers, dewatering problems, requirement for active systems and perpetual care, and often poor mine stability.

(4) Hydrogeologically, existing mines in the Paleozoic salt beds of the Salina Formation appear to have potential as waste repositories. However, concerns about mine stability, future intrusion by humans and restrictions on mineral resources would have to be resolved.

(5) Hydrogeologically and geologically the Goderich salt mine appears to have several advantages over the Ojibway mine.

Based on the above conclusions the following recommendations are made:

(1) A stage 2 feasibility evaluation of the salt mine disposal option should be undertaken with respect to engineering feasibility, social impact, transportation, space requirements, economics, mineral rights and zoning. Should salt mine disposal remain a feasible option at the end of these assessments, the studies as outlined below should be carried out.

(2) Further hydrogeologic, geologic and geotechnical evaluations should include:

   (a) contacting the existing mines to obtain previously unavailable geology, geotechnical and hydrogeology information,

   (b) an inspection of the mines and discussion with mine staff by experienced geologists, hydrogeologists and mine engineers, and

   (c) meetings with representatives of the radioactive waste research programs in North America and Europe to determine the state of the art in salt mine disposal research.

(3) The Ontario Ministry of Labour should be involved in any underground work as sections of Mine Occupational Health and Safety Act and Mine Regulations will govern parts of the work program, and any future disposal operations.

(4) Consideration could be given to carrying out recommendation 2 in parallel with recommendation 1 to refine and expedite the feasibility assessments.

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VOLUME 2

OVERVIEW OF HAZARDOUS WASTE DISPOSAL PRACTICES IN THE UNITED STATES

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PRINCIPAL FINDINGS AND CONCLUSIONS

Landfills

1. Based on this overview of hazardous waste disposal experience in the United States, we have found the engineered landfill to be the most common method of hazardous waste disposal in the U.S.A. The specific engineered landfill types discussed in this report; (a) active conventional engineered landfill saturated zone, (b) active above-ground engineered landfill, and (c) passive engineered landfill, are all feasible designs presently in use in the U.S.A. The selection of a specific type is primarily dependent upon the site.

2. The experience of Geraghty & Miller, Inc., in the U.S. with actual site selections together with the review of current case histories underscores the need for a thorough site selection process. A geologic and hydrologic investigation designed to yield information on the physics of flow in the local ground-water system, ambient ground-water quality conditions, and the effect of the proposed wastes on liners and geologic materials, is a major requirement.

   The need for actual field testing, as opposed to laboratory analyses to determine the permeability of clay and silt deposits, should be emphasized. Fractures and cracks are frequently the most important paths of water movement in such deposits and the importance of these features can only be determined by field techniques. The Wilsonville, Illinois landfill is a case where dependence on laboratory analysis resulted in an incorrect evaluation of the hydrology of the site.

3. Among the several important design features for active engineered landfills, the provision for two separate liners has become a major feature in most new facilities in the U.S. The double liner design requires the control of hydrostatic head not only above the primary (upper) liner but in the zone separating the two liners. The function of the detection/collection system between the liners is to minimize head on the lower liner. When this is accomplished, it makes the lower liner almost impermeable to the movement of fluid. If the leachate collection system has not been properly designed to collect and remove all fluids permeating the upper liner, then the ability of the lower liner to contain leachate is significantly diminished.

4. Although site selection and facility design are of paramount importance in siting a successful landfill, the need for proper and thorough management and maintenance of all control systems is equally important. This is illustrated by the case history on the Florence Landfill in Burlington, New Jersey, where, despite the very favorable site conditions and a leachate collection system, the site has been essentially disqualified because of excessive leachate buildup resulting from failure to properly operate the existing leachate collection and removal system.

5. Many hazardous waste landfills in the U.S.A. accept untreated wastes and until recently, untreated liquid wastes. This has been of particular concern since untreated wastes, especially certain organic chemi-

cals, have been known to alter the permeability of certain types of clays and attack synthetic liners.

Land Treatment

6. Based on experience in the United States, the landfarm method has been limited to the disposal and treatment of certain municipal wastes and hydrocarbon sludges and byproducts. Currently there are no significant applications of this disposal method in the hazardous waste field although research is being undertaken into possible applications. In the U.S., landfarming has been most successfully used in southern areas where climatic conditions are most favorable. For large-scale operations, the land area requirements might be extensive.

Mined Space

7. Although storage of hydrocarbons and disposal of radioactive wastes in mines has been researched extensively, there has been little experience or interest in the use of such facilities for the disposal of hazardous waste. This has been due largely to the high cost of this method and the lack of public interest and acceptance.

Injection Well Disposal

8. Liquid waste disposal in injection wells is regarded as a favorable method in the U.S. and has been used successfully in geologic environments similar to those in Ontario. Data from the States of Illinois and Indiana where several hundred deep injection wells are in use at

the present time show that these installations have been highly successful with minimal environmental impact.

9. The success of an injection well is highly dependent upon critical hydrostatic and water chemistry factors that must be evaluated in advance of the design and installation. Where these factors have been taken into consideration, facilities in the U.S.A. have generally performed successfully with minimal environmental impact.

Regulations

10. In the U.S., hazardous waste regulations are guided by the standards established by the USEPA and these have been summarized and discussed in this report. Although EPA has established design standards for facilities, they are somewhat flexible and allow for exemptions under certain circumstances. Several states have adopted their own hazardous waste regulations which are generally based on the Federal requirements but are more stringent in certain areas such as landfill design and siting, and restriction of certain types and quantities of hazardous wastes. The hazardous waste regulations of the State of New Jersey provide a good example of the type of work being done.

On the state level the Environmental Protection Agency is currently studying the legislative and regulatory work that is being done by the individual states. It is the concensus among many individuals in the regulatory agencies interviewed that the Federal Government will follow the State's leads in making the regulations more stringent in certain areas on the premise that it would encourage industry to develop newer and more efficient means of waste treatment (or pretreatment) and disposal.

11. Within the body of Federal regulations governing hazardous waste disposal in the U.S. there are no specific design requirements for the construction and use of underground mines. The regulations simply require that the facility be designed to minimize adverse environmental impacts.

    At the present time the USEPA is considering the total ban on hazardous waste disposal and storage in underground mined space and natural caverns.

12. In the U.S., underground injection is governed by UIC (Underground Injection Control) Regulations, which were an outgrowth of provisions contained in the Safe Drinking Water Act of 1974 for controlling the use of injection wells. These regulations set standards for the selection of appropriate sites and design and operation of the installations.

OVERVIEW OF HAZARDOUS WASTE DISPOSAL PRACTICES IN THE UNITED STATES

INTRODUCTION

In January, 1984 Geraghty & Miller, Inc. was retained by Gartner Lee Associates Limited to provide an overview of hazardous waste disposal practices and regulations in the United States. The results of this study, together with corresponding work by Gartner Lee Associates, are to be used in support of Ontario Waste Management Corporation's efforts to formulate a hazardous waste disposal plan for the province and to select a suitable site or sites. In this report Geraghty & Miller, Inc. has summarized current state-of-the-art waste disposal practices in the United States, including landfilling, land treatment, disposal into specially modified or constructed underground mines, and disposal into underground injection wells. Important technical considerations of waste disposal alternatives and an overview of current regulatory controls are also included.

The study results indicate that hazardous waste disposal by landfilling is the prevailing practice in the United States. Disposal into underground mines, a highly specialized method, is generally reserved for such materials as radioactive wastes. Deep well injection has found acceptance only in areas of highly favorable subsurface conditions.

LANDFILLS

In the United States disposal in specially engineered landfills is currently the preferred and most practical method of hazardous waste disposal. Land treatment is used to only a limited extent in warm, southern climates and is generally reserved for hydrocarbon-based products. In this section of the report we have provided an overview of these disposal methods. The work is based on a review of the current literature, first-hand interviews with regulators and on information available in Geraghty & Miller, Inc. company files. We have also included a summary of pertinent Federal regulations.

In contrast to the many reported environmental impacts and problems resulting from domestic waste disposal in sanitary landfills, the properly designed, constructed and managed engineered landfill appears to be the best method available today for disposal of hazardous wastes. Such facilities have been successfully developed in the United States on the basis of thorough hydrogeologic, engineering, and environmental studies combined with proper monitoring and management. At locations in the United States where these criteria have been followed, the resulting hazardous waste disposal facilities have generally been highly successful in preventing adverse impacts on the environment including the ground-water system.

In 1980 there were a total of 127 facilities in the United States commercially storing and disposing of hazardous wastes. Of the total of 127 facilities, 36 were operated by nine major firms1) in the field. In

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[1] Chemical Waste Management, Browning-Ferris Industries, Rollins Environmental Services, SCA, IT, US Ecology, CECOS, Conversion Systems, Chem-Clear.

1980 these firms handled 3.7 million wet metric tons of waste (WMT) which accounted for approximately half of the total that was disposed of at commercial facilities. The 127 facilities represent six different waste management options which are: Landfill, Land Treatment/Solar Evaporation, Incineration, Chemical Treatment, Resource Recovery, and Deep Well Injection.

Landfilling, however, accounted for 37.5 percent of all wastes handled at the 127 facilities followed by chemical treatment at 32.6 percent and then deep well injection, land treatment/solar evaporation, resource recovery, and incineration in decreasing order. For the nine major firms listed above, in 1980 landfilling accounted for 59.5 percent of wastes managed with the relative uses of the remaining options in the same order as for all 127 facilities.

Therefore, it appears that despite increasingly more stringent regulations on the state and Federal level, landfilling of hazardous wastes will continue to be the major method of waste management in the foreseeable future. However, permitting of sites will require careful site selection, favorable hydrogeologic conditions, and state-of-the-art engineering design. Public opposition to a landfill siting will undoubtedly remain at a high level and therefore "overdesign" of a site may be required to obtain approval.

The limited number of case histories that have been collected for this study only provide a cursory look at current practices in the United States and cannot be used to statistically evaluate the success or failure of a particular design, hydrogeologic setting, or combination of these factors. They do, however, provide an insight into the various components that presently comprise the state-of-the-art in hazardous waste landfilling in the U.S.A.

Active Engineered Design Concepts

An active engineered or "secure" landfill is one which incorporates the following design components:

a) a cap or cover over the waste material to minimize the generation of leachate produced by reducing precipitation infiltrating the waste.

b) a leachate collection system to control the quantity of leachate and collect it for treatment.

c) a liner system, utilizing natural in situ clays and/or placement of one or more synthetic or clay liners to attenuate the migration of leachate into the surrounding soils and ground-water system.

One interesting and new type of landfill cover presently under consideration is a polyester based canopy to cover the landfill during its operation. The polyester-based canopy has not to our knowledge been used in the United States. However, because the production of leachate from a landfill is a major environmental concern requiring sophisticated engineering design and thorough and consistent operation and maintenance practices to mitigate the leachate's effect on the environment, method(s) to minimize or prevent leachate production would be a key factor in the successful siting and managing of a hazardous waste landfill. Therefore, the proposed CECODOME (see Attachment A for details) should be carefully considered and the field experience should be considered after its planned construction in early 1984.

Two types of active engineered landfill designs more commonly used in the United States are: above ground engineered landfills located above grade and above the water table, and conventional active engineered landfills with excavated portions below grade and in some environments below the water table.

The concepts of the more common active engineered landfill designs are discussed below. However, one thing all these designs have in common is that they are located on fine-grained, low permeability soils.

Above Ground Engineered Landfill

This design involves encapsulation of waste above the water table. These types of landfills are constructed above ground with a low permeability liner(s) at the base covered with low permeability material (an infiltration barrier) above the waste. The key objectives for the successful operation of above-ground landfills are minimization, attenuation, and collection of leachate within the waste management facility (cell). These are becoming common types of hazardous waste landfills in the United States today.

Conventional Active Engineered Landfill

This concept involves the placement of waste in an excavation at or below the water table. In drier climates the water table could be well below the landfilled waste. These types of landfills may or may not utilize a liner to attenuate leachate. The success of these landfills depends on the maintenance of a negative head differential between the leachate level in the waste areas and the surrounding water table. This method insures that ground-water flow is continuously toward the landfill so that leachate cannot escape. Landfills in the water table rely to a great extent on the proper engineering and operation of leachate collection systems. These are presently the most common types of hazardous waste landfills in areas of humid climates within the U.S.A.

Passive Engineered Landfill Design Concept

This concept allows leachate to migrate offsite from an unlined facility at a controlled rate and in a predictable direction. Natural processes such as dispersion, dilution, attenuation, and degradation are relied upon to reduce contaminant concentrations to acceptable levels beyond the facility. Covers and leachate collection systems may or may not be used. The success of this type of facility depends almost entirely on selection of the proper site. The hydrogeology at a prospective site must be understood in detail before construction and operation of a passive engineered landfill is undertaken. One type of passive engineered landfill entombment of wastes in specially designed facilities deep in the overburden, is not widely employed in the United States and therefore very little information is available on this method.

A series of 11 case histories has been compiled to illustrate the types of hazardous waste landfills being used in the United States and to examine the reasons for their success or failure. Information concerning landfill design, history, and hydrogeologic setting was researched through published reports and interviews with individuals in the waste management and design profession, state and Federal regulatory agencies, and experts in the academic field. Table 1 summarizes the hydrogeologic setting, design components, and relative successes or failures of each hazardous waste landfill site.

An important point to keep in mind regarding these case histories is that Geraghty & Miller, Inc. did not make an independent evaluation of the monitoring and other pertinent data for each site in order to determine success or failure of a site relative to its impact on ground water. Reports or opinions of others were depended on for this evaluation. During this brief literature search, case histories of hazardous waste disposal through land treatment (sludge tilling or spray irrigation) were not found for states with humid climates similar to Ontario.

Table 1. Summary of Hazardous Waste Landfill Case Histories in the United States.

Name of Landfill	State	Year Operation Began	Landfill Type	No. liners/type	Utilizes Low Permeability Formation (unlined)	Above or Below Water Table	Leachate Collection System	Geologic Setting	Negative Impact on Ground-Water System	Comments
Kettleman Hills	California	1979	Modified active conventional engineered landfill	None	X	above	yes	thick clay formation	no	arid setting <5" rain/yr.
Emelle Treatment Center	Alabama	Unknown	Modified active conventional engineered landfill	None	X	above	yes	thick clay formation	no	
Scientific Landfill #7 (SCA)	New York	1979	Active conventional engineered landfill	2/clay over synthetic		above	yes	glacial till	no	site filled to capacity (closed)
CECOS #3	New York	1980	Above ground engineered landfill	3/synthetic between 2 clay layers		above	yes	till over dolomite	no	
Wilsonville	Illinois	1976	Passive conventional engineered landfill	None	X	below	no	glacial till	potentially	site ordered exhumed
DuPont	New Jersey	1979	Active engineered landfill probably above ground	2/synthetic		above	yes	silty sand (alluvium ?)	no	primary (upper) liner leaking
Toms River	New Jersey	1977	Active conventional engineered landfill	2/synthetic		above	yes	fine sands	no	primary (upper) liner leaking
J.T. Baker	New Jersey	1977	Active conventional engineered landfill	2/synthetic		above	yes	silty sand over till	no	primary (upper) liner leaking
Florence	New Jersey	1970	Modified active conventional engineered landfill	None	X	below	yes	clay formation	no	co-disposal with municipal wasts, site closed, on EPA superfund list
Glades Road	Florida	1978	Modified above ground engineered landfill	None	X	above	yes	silty sand over clay	no	municipal waste only
Anonymous Site A	New Jersey	1978	Above ground engineered landfill	3/2 clay over 1 synthetic		above	yes	dredge spoil (fill) over clay	no	primary (upper) liner leaking

Note: Monitoring wells are used at all landfills to determine if site is contributing leachate to the ground-water system.

Summary of Case Histories

Name: Kettleman Hills Landfill

1. Landfill Type: Modified active conventional engineered landfill set above the water table.

2. Location: Kettleman City, California

3. Ownership and Regulation:

   (a) Ownership: Chemical Waste Management, Inc.

   (b) Regulation: U.S. EPA under the Resource Conservation and Recovery Act (RCRA), Permits from the State Department of California Health Services, Regional Water Quality Control Board, the California Air Resources Board, and the Kings County Planning Department.

4. Operating Period: The Kettleman site was first granted a Class I permit for disposal of hazardous waste material in February 1979 and it is still in operation.

5. Operational Status: Currently active.

6. Method of Operation: Wastes are stored in drums within cells.

7. Wastes Disposed: The Kettleman Hills facility accepts for on-site disposal nearly all solid, semi-solid, and liquid wastes. Exceptions are liquid PCBs of more than 50 parts per million (ppm) concentrations, capacitors containing more than three pounds of PCBs, Class A

explosives, radioactive materials, and infectious biological agents. Wastes containing PCBs in excess of the levels mentioned above are accepted and stored on-site in a specially designed storage facility. Liquid wastes undergo a form of treatment for processing and solidification prior to disposal at the Kettleman Hills site. No hazardous wastes are landfilled in a liquid state. The following treatment and disposal techniques are available at the Kettleman Hills site.

(a) Chemical fixation/solidification.
(b) Drum decanting.
(c) Cyanide treatment.
(d) Supplemental fuel recovery.
(e) Solar evaporation.
(f) Land farming.
(g) Engineered landfill.

8. Hydrogeology: The site is located in an arid region of California where depth to water is well below the bottom of the landfill. The landfill itself is excavated in a thick clay bed above layers of silt stone and shale.

9. Climate: Arid.

10. Design Components: The landfill does not have a synthetic liner but relies on the natural clay formation. It has an underdrain leachate collection system.

11. Monitoring: The landfill site has a series of monitoring wells that are required under the Resource Conservation and Recovery Act. Well locations are located just off-site in both upgradient and downgradient directions.

12. Success/Failure Scenarios: There is no evidence that leachate is escaping from the landfill area.

13. Mitigation: Mitigation not necessary at the site.

14. Source: Chemical Waste Management, Inc. Brochure. Telephone Conversation with Robert Reinke, Chemical Waste Management, Inc.

Name: Emelle Treatment Center

1. Landfill Type: Modified active conventional engineered landfill above the water table.

2. Location: Emelle, Alabama

3. Ownership and Regulation:

   (a) Ownership: Chemical Waste Management, Inc.
   (b) Regulation: U.S. EPA.

4. Operating Period: Unknown.

5. Operational Status: Currently in use.

6. Method of Operation: Wastes are stored in cells.

7. Wastes Disposed: The Emelle landfill accepts disposal of all types of solid and liquid wastes with the only major exceptions being Class A explosives, radioactive wastes, and infectious biological agents. Liquid PCBs over 500 ppm concentrations are accepted for storage in Emelle tanks with a capacity of 5.7 million liters. Major categories of wastes treated and disposed include PCBs, acid solvents, heavy metal solutions, sludges, chlorinated and other organics, EP toxicity listed wastes, bulk solids including contaminated soil.

8. Hydrogeology: The site is excavated within a natural clay layer which is reportedly 213 meters thick. It is in a semi-arid region of Ala-

bama and the depth to the water table is well below the bottom of the landfill.

9. Climate: Semi-arid.

10. Design Components: The landfill is unlined and relies on the natural clay to contain leachate. Leachate is collected in an underdrain system and treated onsite.

11. Monitoring: A network of wells are used to monitor the impact of the site on the ground-water system.

12. Success/Failure Scenario: There is no evidence of leachate escaping from the landfill.

13. Mitigation: Mitigation not necessary at the site.

14. Source: Chemical Waste Management, Inc. Brochure. Telephone Conversation with Robert Reinke, Chemical Waste Management, Inc.

Name: Scientific Landfill #7

1. Landfill Type: The site is an active conventional engineered landfill.

2. Location: Model City, New York.

3. Ownership and Regulation:

   (a) Ownership: SCA Chemical Wastes Services Corporation

   (b) Regulation: U.S. EPA and New York State Department of Environmental Conservation (NYDEC).

4. Operating Period: SLF #7 began operation in 1979, was filled to capacity, and was closed in 1982. SCA is now operating Scientific Landfill #10. SLF #11 is under construction.

5. Operational Status: Closed.

6. Method of Operation: Wastes are stored in independent cells.

7. Wastes Disposed: Treated industrial wastes, both solid and liquid.

8. Hydrogeology: The site is situated on deposits of interbedded clays and tills with low permeability. The site is built below the water table. The base of the excavation is underlain by a minimum of five feet of glaciolacustrine clay with a maximum permeability of 1×10^{-7} cm per second. The walls of the landfill consist of natural clay (glacial till). The permeabilities in unjointed areas are approximately 6×10^{-8} cm/sec; where the clay is jointed the permeability averages 1×10^{-6} cm/sec.

9. Climate: Temperate (Upstate New York).

10. Design Components: The landfill utilizes the natural clay layer at its base overlain by a synthetic liner (Hypalon) above which a 0.6 meter layer of clay is placed which forms the working surface of the landfill. A leachate collection system is built on top of the upper clay layer and consists of a network of gravel-packed and perforated 203 millimeters diameter clay pipes with vertical standpipes for leachate removal. Leachate is treated on-site. The site, which is now closed, has a clay cap. It is uncertain whether gas collection systems are being used.

11. Monitoring: Leachate levels are monitored continuously within the leachate removal system. A series of monitoring wells are located at both upgradient and downgradient points from the site.

12. Success/Failure Scenarios: There is no evidence of leachate migration from Landfill #7. Scientific Landfills 1 through 6 were in operation between 1971 and 1977. All six landfills were built below ground surface at or slightly above the water table. Synthetic liners and leachate collection systems were used in all six landfills, but gas collection systems were not. The designs and waste disposal practices in the older fills were significantly different from Landfill #7, where modern disposal means (upright and tight packing of drums) are used. Scientific Landfills 1 through 6 have since had operational and design failures such as generation of organic phase leachate, differ-

ential settlement, desication cracks in the liners, and erosion of the caps leading to high leachate levels within the waste area. The NYDEC ordered leachate be removed from the older landfills and treated. There is no evidence the leachate is escaping into the ground-water system in the vicinity of the six landfills.

13. Mitigation: Mitigation not necessary at the site.

14. Source: Reprints of reports written by Peter N. Skinner, P.E., NY State Law Department and a report by Robert D. Mutch, Jr., Wehran Engineering. Telephone Conversation with Peter N. Skinner. Telephone conversation with Robert D. Mutch of Wehran Engineering.

Name: CECOS #3

1. Landfill Type: The CECOS Landfills (#1, #2, and #3) are above-ground engineered landfills.

2. Location: Niagara Falls, New York.

3. Ownership and Regulation:

   (a) Ownership: Chemical Waste Realty

   (b) Regulation: U.S. EPA and New York State Department of Environmental Conservation (NYDEC).

4. Operating Period: Landfill #3 began in 1980 and is currently in use. Applications for Landfills #4 and #5 were pending as of 1980. Landfills #1 and #2 are closed.

5. Operational Status: Continuous.

6. Method of Operation: Wastes are stored in cells.

7. Wastes Disposed: Liquid and solid wastes.

8. Hydrogeology: The site rests within a thin veneer of glacial till set directly above limestone bedrock (dolomite). Water table is approximately at the base of the landfill.

9. Climate: Temperate (Upstate New York).

10. Design Components: The CECOS facility utilizes three liners, synthetic Hypalon liner is sandwiched between two layers of clay. Leach-

ate is collected in an underdrain system above the primary clay as well as in stand pipes and mid-level drains. Leachate is treated onsite. Daily backfill of alkaline material is used. Closed landfills utilize clay covers. Gas collection systems are used.

11. Monitoring: Ground-water monitoring at the landfill is accomplished through a series of wells outside of the waste areas. The leachate levels are monitored through vertical standpipes within the fill area.

12. Success/Failure Scenarios: There is no evidence to show that Landfill #3 has contributed leachate to the ground-water system. According to Skinner, background ground-water quality makes assessment of the landfill's impact on the ground-water system difficult. CECOS International Landfills 1 and 2, which have been closed since 1978 and 1979, respectively, have not had any major operational difficulties. Maintenance problems with the leachate removal systems for Landfills 1 and 2 have been reported. The design of Landfills 1, 2, and 3 is virtually the same; the only difference is that larger diameter standpipes for leachate collection were used in Landfill 3 to correct drainage problems experienced in Landfills 1 and 2.

13. Mitigation: Mitigation is not necessary at the site.

14. Sources: Reprint of reports by Peter N. Skinner: N.Y. State Law Department. Telephone conversation with Peter N. Skinner (NYSLD).

Name: Wilsonville Landfill

1. Landfill Type: Passive conventional engineered landfill intersecting the water table at some locations.

2. Location: Wilsonville, Illinois.

3. Ownership and Regulation:

   (a) Ownership: SCA Services Inc.

   (b) Regulation: Illinois State Environmental Protection Agency and the U.S. Environmental Protection Agency.

4. Operating Period: The landfill began operation in 1976 and was ordered closed in March 1982.

5. Operational Status: Closed.

6. Method of Operation: Wastes were stored in cells and covered with clays and native soils.

7. Wastes Disposed: Drummed industrial wastes, both liquid and solid.

8. Hydrogeology: The landfill is underlain by 15 to 30 meters of glacial till which rests atop clayey shale bedrock of Pennsylvania age. The till is composed primarily of clay and silt. Geologic logs reported by the Illinois State Geological Survey indicated that the upper 9 to 12 meters of the till was fractured and contained discontinuous lenses of sand. Hydraulic conductivity tests performed on the glacial till were completed by laboratory analyses of soil cores collected during

construction of the landfill and in the field by injection testing after the facility was closed. Comparison of the field test results with the laboratory results indicated conductivities determined by injection testing to be 2 to 3 orders of magnitude greater than the laboratory results (10^{-4} cm/sec vs. 10^{-7} cm/sec in the upper fractured till and 10^{-7} cm/sec vs. 10^{-9} cm/sec in the lower unfractured till).

The discrepancy between the field and laboratory results may have led to the misinterpretation of the hydraulic conductivity of the till originally when the landfill was being designed.

The Town of Wilsonville obtains its water supply from a surface water reservoir located in an adjacent town. There are no ground-water supplies in the vicinity of the landfill.

The water table exists below the bottom of most trenches, however, several trenches may intersect the water-table seasonally during wet periods.

9. Climate: Temperate.

10. Design Components: The landfill is made up of 26 trenches or cells clustered in two general areas. The landfill is a trench and fill design which utilizes the natural clay formation to attenuate leachate. A compacted clay liner was used to supplement the native till in at least one of the 26 trenches. A peripheral drain below grade was used to collect highly acidic and mineralized leachate and surface runoff

from a nearby coal refuse pile. The leachate from the coal pile is mitigated by the high buffering capacity of the local soils and has no apparent effect on the wastes within the trenches. A clay cap was used to cover the trenches after they were filled.

11. Monitoring: After the Illinois State Supreme Court ordered the Wilsonville landfill closed and exhumed, an extensive monitoring program was undertaken which included a field investigation designed to detail the local geology and its hydraulic properties and to determine the impact of the landfill on ground-water quality. As it is being exhumed, the condition of the landfill itself is being monitored, such as the integrity of the clay covers (caps), drums, wastes, trench walls, etc. The monitoring program is continuing and is currently in progress.

12. Success/Failure Scenarios: The landfill was ordered closed and exumed because of its proximity to the Town of Wilsonville. The landfill was deemed by the courts as a "risk to the environment and a public nuisance." Migration of contaminated ground water through the shallow till (fractured zone) was documented one month prior to the landfills' closure and the seepage rate was found to be 100 to 300 times faster than had been predicted by the landfill engineers. The results to date are not conclusive as to the exact cause or causes of the landfills failure. However, a number of reasons are being investigated. They are: 1) misinterpretation of fracturing within the upper clay till, therefore, inaccurate predictions of hydraulic con-

ductivity; 2) sand lenses which were more extensive than had originally been reported; 3) land subsidence caused by nearby mining operations (approximately 91 meters below the site) resulting in sinkholes within the trenches and clay caps; 4) chemical breakdown of clays caused by certain wastes.

13. Mitigation: Wastes from the landfill are being exumed and taken to an approved landfill for proper disposal.

14. Sources: Griffin, R.A. and others, 1983, Investigation of Clay Soil Behavior and Migration of Industrial Chemicals at Wilsonville, Illinois. Illinois State Geological Survey; Proceedings of the 9th Annual Research Symposium of the Solid and Hazardous Waste Research Division, (USEPA) Cincinnati, Ohio.

    Griffin, R.A. and others, 1984, Migration of Industrial Chemicals and Soil Waste Interactions at Wilsonville, Illinois, Illinois State Geological Survey; Proceedings of the 10th Annual Research Symposium of the Solid and Hazardous Waste Research Division, (USEPA) Fort Mitchell, Kentucky.

Name: DuPont Landfill

1. Landfill Type: The DuPont facility is an active engineered landfill probably above-ground.

2. Location: Deep Water, New Jersey.

3. Ownership and Regulation:

   (a) Ownership: E.I. DuPont Company, Inc.

   (b) Regulation: New Jersey Department of Environmental Protection.

4. Operating Period: The site began accepting sludge in January of 1979. The site is still in operation.

5. Operational Status: Continually active.

6. Method of Operation: Wastes are contained in cells.

7. Wastes Disposed: The landfill accepts a variety of drummed solid chemical wastes and bulk solid chemical wastes.

8. Hydrogeology: Silt and sand (alluvium ?).

9. Climate: Temperate (New Jersey).

10. Design Components: The DuPont landfill is an engineered landfill, but it is not certain whether it is above or below ground. The landfill is lined with two Hypalon liners. The site also utilizes an underdrain system for leachate collection and leachate collection sumps to monitor leakage.

11. Monitoring: A series of monitoring wells were placed at locations in the upgradient and downgradient directions in the vicinity of the landfill.

12. Success/Failure Scenarios: Although the primary liner was determined to be leaking, there is no evidence that the landfill itself is contaminating the local ground-water system.

13. Mitigation: Mitigation has not been deemed necessary at the site.

14. Sources: Reports by Peter Montague of Princeton University Center for Energy and Environmental Studies.

Name: Toms River Landfill

1. Landfill Type: Conventional active engineered landfill.

2. Location: Dover, New Jersey.

3. Ownership and Regulation:

   (a) Ownership: Toms River Chemical Company.

   (b) Regulation: New Jersey Department of Environmental Protection.

4. Operating Period: The site began operation in 1977.

5. Operational Status: Active.

6. Method of Operation: Wastes were stored in cells.

7. Wastes Disposed: Solid wastes from in-house manufacturing, which include epoxy residues, clarification residues, and distillation residues. Some of the wastes are drummed, others transported in bulk.

8. Hydrogeology: The site is located within the Cape May Formation composed primarily of fine sands. The layer of sand itself is roughly between 24 and 30 meters thick. Landfill is above the water table.

9. Climate: Temperate.

10. Design Components: The landfill utilizes two PVC liners to contain leachate and an underdrain system between the two liners for leachate collection. The leachate is collected in sumps.

11. Monitoring: The quantity of leachate is monitored in collection sumps. Ground-water monitoring wells are being used at the facility.

12. Success/Failure Scenarios: Although the primary liner was found to be leaking, there is no evidence that the landfill is contributing leachate to the ground-water system.

13. Mitigation: Mitigation has not been deemed necessary at the site.

14. Sources: Reports by Peter Montague of Princeton University Center for Energy and Environmental Studies.

Name: J.T. Baker Landfill

1. Landfill Type: The landfill is an active conventional engineered landfill.

2. Location: Phillipsburg, New Jersey.

3. Ownership and Regulation:

   (a) Ownership: J.T. Baker Chemical Company.

   (b) Regulation: New Jersey Department of Environmental Protection.

4. Operating Period: The J.T. Baker Chemical Company landfill began accepting wastes in 1977.

5. Operational Status: Active.

6. Method of Operation: Wastes are stored in lined cells.

7. Wastes Disposed: Industrial hazardous wastes.

8. Hydrogeology: The site is constructed in an area underlain by approximately 4 meters of silty sand over 8 meters of glacial till which is directly above a dolomite bedrock. The site is well above the water table which is approximately 18 meters below land surface.

9. Climate: Temperate (New Jersey).

10. Design Components: The landfill uses two PVC liners to contain leachate. An underdrain system is used between the liners which drains

leachate into a collection sump. The quantity of leachate is monitored in the collection sump.

11. Monitoring: Sumps used to collect leachate are monitored at the site. Ground-water monitoring wells are being used at the facility.

12. Success/Failure Scenarios: Although a leak was detected in the primary PVC liner there is no evidence that the site is leaking leachate into the local ground-water system.

13. Mitigation: Mitigation has not been deemed necessary at the site.

14. Sources: Reports by Peter Montague of Princeton University Center for Energy and Environmental Studies.

Name: Florence Landfill

1. Landfill Type: The Florence landfill is a modified active conventional engineered landfill. The landfill intersects the water-table zone within the Merchantville clay formation.

2. Location: Florence, New Jersey.

3. Ownership and Regulation:

   (a) Ownership: Florence Landfill Recontouring Inc.

   (b) Regulation: New Jersey Department of Environmental Protection.

4. Operating Period: The landfill operated from 1970 to 1981.

5. Operational Status: Closed.

6. Method of Operation: Hazardous wastes were co-disposed with municipal wastes. Hazardous materials were stored in unlined cells.

7. Wastes Disposed: Muncipal wastes were co-disposed with industrial wastes.

8. Hydrogeology: The Florence landfill is situated and installed in the Merchantville Clay (12 to 18 meters thick at the site) which is overlain by a thin veneer of glacial sand. The Merchantville clay overlies the Magothy-Raritan aquifer system. The permeability of the Merchantville Formation ranges between 1.6×10^{-6} cm per second to 7.3×10^{-7} cm per second. The landfill itself intersects the water table within the Merchantville Clay.

9. Climate: Temperate (New Jersey).

10. Design Components: The Florence landfill is unlined utilizing a natural clay to contain leachate. The landfill has a leachate collection system which consists of lateral pipes at the base above the clay which drain into several sumps. However, the sumps were pumped infrequently leading to a large build-up of leachate levels within the landfill.

11. Monitoring: A network of monitoring wells are located in areas upgradient and downgradient of the landfill in both the shallow zones in the clay and in the deep water-bearing zones. Monitoring wells are also located within the landfill to monitor leachate levels.

12. Success/Failure Scenarios: There is no apparent leakage of contaminants beyond the property boundaries. Monitoring data from deep wells (Magothy Raritan Formation) indicate that the contaminants have not migrated through the natural clay to the underlying aquifer. However, surface leachate seeps have occurred due to erosion of the dikes surrounding the landfill and infrequent operation of the leachate collection system.

13. Mitigation: This site is currently on the EPA Superfund list due in part to the levels and quality of leachate in the landfill.

14. Sources: Geraghty & Miller, Inc. reports.

Name: Glades Road Landfill

1. Landfill Type: Modified above ground engineered landfill.

2. Location: St. Lucie County, Florida

3. Ownership and Regulation:

   (a) Ownership: St. Lucie County

   (b) Regulation: Florida Department of Environmental Regulation and the U.S. Environmental Protection Agency.

4. Operating Period: The site has been in operation from 1978 to present.

5. Operational Status: Continual.

6. Method of Operation: Wastes are stored in individual cells.

7. Wastes Disposed: Muncipal solid wastes and construction debris.

8. Hydrogeology: The site is underlain by approximately one meter of silt and sand followed by a layer of sandy to silty clay that is ap-approximately two meters thick. The clay rests above a shallow artesian aquifer composed of sand and silt. The water table occurs within the clay layer. Head measurements taken in the shallow water-table aquifer and the artesian aquifer indicate that a vertical gradient exists from the water-table aquifer downward towards the artesian aquifer.

9. Climate: Semi-arid, approximately 356 millimeters of rain per year.

10. Design Components: The 101 square hectometers site is unlined and relies on the natural clay layer to attenuate leachate. A berm and ditch encircles the entire site. Surface runoff is collected in the ditch. The site utilizes an underdrain system which feeds into two collection sumps. Leachate is periodically removed from the sumps into two lined ponds for biological oxidation treatment.

11. Monitoring: Six shallow wells are located just offsite to monitor the impact of the landfill on the ground-water system.

12. Success/Failure Scenarios: There is no evidence to indicate that leachate is being contributed to the ground-water system by the landfill.

13. Mitigation: Mitigation has not been deemed necessary at the site.

14. Sources: Geraghty & Miller, Inc. reports.

Name: Anonymous Site A

1. Landfill Type: Above-ground engineered landfill.

2. Location: New Jersey.

3. Ownership and Regulation:

   (a) Ownership: Anonymous.

   (b) Regulation: New Jersey Department of Environmental Protection.

4. Operating Period: The site went into operation in 1978 and is still being used.

5. Operational Status: Continuously active.

6. Method of Operation: Sludges are deposited on a sand bed which covers the upper clay liner and covered with a synthetic membrane to reduce odors; dry solid waste is covered periodically with dredge material.

7. Wastes Disposed: Sewage sludge and dry chemical.

8. Hydrogeology: The landfill is directly underlain by dredge spoils from an adjacent River. The dredge material rests atop a 9 to 18 meters thick clay confining unit. The clay layer lies above 36 to 61 meters of unconsolidated sands and gravel. The landfill and its liners are above the water table during the entire year.

9. Climate: Temperate.

10. Design Components: The landfill is underlain by two clay layers, an 457 to 635 millimeter primary (upper) layer and a 305 millimeter secondary (lower) layer. Between the two clay layers is a 0.3 meter thick sand layer. Directly beneath the lower clay is a polyester fiber called BIDIM. BIDIM was used to reduce the chance of uneven settling of the subsoil which would destroy the integrity of the clay liner. There is a leachate collection system above the primary clay layer and a leachate detection/collection system between the two clay liners in the sand. A berm and ditch encircles the landfill. The ditch receives surface runoff and drainage from above the primary clay layer. The underdrain systems feed into collection sumps outside of the landfill. Leachate is treated on-site. Cover material is used during operation.

11. Monitoring: A series of monitoring wells were installed outside of and encircling the landfill. Sumps which collect leachate from the underdrain systems are monitored for the quantity and quality of water.

12. Success/Failure Scenarios: There is no evidence of hazardous constituents leaking and reaching the local ground-water system. Seepage through the primary clay liner was detected during monitoring of the underdrain system.

13. Mitigation: Mitigation has not been deemed necessary at the site.

14. Sources: A report by Geraghty & Miller, Inc.

LAND TREATMENT

EPA considers land treatment to be a proven technology for treating and disposing of some hazardous wastes. Land treatment involves the application of wastes on the soil surface or the incorporation of the waste into the soil in order to degrade, transform, or immobilize hazardous constituents. It relies on physical, chemical, and biological processess occurring in the upper layers of the soil rather than on liners or leachate collection systems to control the release of contaminants to ground water.

The U.S. Environmental Protection Agency (Robert S. Kerr Environmental Laboratory) in cooperation with the University of Okalahoma, will begin a two-year study in the summer of 1984 at a 40 square hectometer land treatment test facility in Ada, Oklahoma. The purpose of the study will be to evaluate the effectiveness of land farming selected hazardous wastes and state-of-the-art land farming techniques.

Waste streams that will be tested at the site include petroleum refinery wastes, pesticide wastes, wood preservation wastes, paint sludges, and military wastes. These substances will be applied to the ground and tilled into the soils at controlled loading rates which will be varied to determine the most effective application rates for specific compounds. Surface water, ground water, soil water, and air quality parameters will be monitored at the site as will the biochemical degradation rates of the wastes in the soils.

Given the proper soil conditions and waste characterisitics, land treatment can be very effective if the treatment units are properly operated. Maintenance of proper soil pH to optimize microbial action and metal immobilization, careful management of waste application rates to prevent exceeding the soil treatment capacity, and control of surface runoff to prevent untreated wastes from leaving the facility, are key operations. In addition, well-managed facilities must perform effective monitoring of the unsaturated zone to demonstrate that the treatment processes are successful. Ground-water monitoring is also required at the boundaries of the waste management area to insure that the ground-water protection standard is met.

LOCATION STANDARDS

This section summarizes three studies in which Geraghty & Miller, Inc. has been involved that deal with the subject of location factors and how they may affect design and operation practices. These studies give an indication of present concerns on behalf of EPA and of industry. They include the following: 1) a study of low-permeability sites for the Office of Research and Development (ORD), 2) liner-location study for the Land Disposal Branch (LDB), and 3) risk/benefit liner-location study for the Economics and Policy Analyses Branch.

The purpose of the study for ORD was to examine and discuss technical considerations associated with locating surface impoundments and landfills in saturated earth materials of low permeability (low-K) soils. This central issue was divided into several sub-issues: siting, design, construction, post-closure, and corrective action. The emplacment of waste into saturated soils of low permeability is currently being permitted by several states in humid regions where the water table is naturally close to the land surface. EPA considers that such settings may provide enough natural containment potential to warrant permitting, even though it is not strictly allowed in Part 264. Geraghty & Miller, Inc.'s study focused on theoretical concepts rather than case histories. the following is a list of the more important findings and conclusions of that study:

1) Unlined facilities that terminate in saturated low-K soils can provide equivalent or greater levels of containment provided that heads within the facility are kept low by leachate collection systems.

2) Failure of low-K soils in the form of ruptures of the bottom of open excavation by hydraulic pressures or by slope failures are both more common in saturated than unsaturated low-K soils, however, both situations can be prevented with field studies and modeling efforts that can lead to stable designs.

3) The bathtub effect can occur in both saturated and unsaturated low-K soils; however, it may be somewhat less pronounced when soils are unsaturated.

4) Based on travel-time criteria, emplacement of waste into saturated low-K soils provides a greater degree of protection than emplacement in equivalent unsaturated soils.

5) An assessment of literature relevant to attenuation mechanisms in low-K soils indicates no significant advantage exists for emplacement of wastes into unsaturated as opposed to saturated low-K soils.

6) Corrective actions involving fluid removal with wells or encapsulation with slurry wells are marginally feasible for most low-K materials.

The purpose of the study for the LDB was to identify and evaluate facility and location "factors" that affect release and transport of contaminants through the subsurface environment. A simulation modeling approach was selected by EPA to provide a quantitative analyses in which each factor would be assigned a range of values on the basis of data generated at actual regulated facilities. Performance measures used for comparison of combinations of facility and location factors included the following: 1) first appearance of contaminants at either the water table or a hypothetical exposure point downgradient, 2) time to reach, and value of, peak concentrations at the water table and at hypothetical points downgradient, and 3) leachate distribution within the unsaturated zone or contaminant distribution within the saturated zone at the end of a 200-year simulation time.

Results of this study included the following: 1) identification of location and facility factors, 2) indentification of settings that limit, or alternatively enhance, migration of contaminants, 3) preliminary relationships between facility and locational factors. Facility factors included elements such as facility type, climate, permeability, and thickness of liners, failure modes of synthetic liners, and efficiency of leachate collection systems. Location factors included such items as depth to water table, hydraulic and retardation properties within the unsaturated zone, permeability and thickness of uppermost saturated materials, retardation properties of the saturated zone, position of the facility in a recharge or discharge zone, and stressing of an aquifer by pumping.

For a given climate and facility type, the permeability of clay liners appears to be the most important facility factor. Other important facility factors include the failure mode assumed for the synthetic liner and the presence and efficiency of a leachate collection system. From a consideration of location factors alone, the best settings for hazardous waste management facilities appear to have the following characteristics: 1) thick, homogeneous, low-permeability unsaturated zone; 2) thick, homogeneous, areal extensive, low-permeability saturated zone, and 3) sediments having good retardation potential.

When the simulation of facility performance was coupled to performance of the subsurface system, the performance of two locational settings were relatively insensitive to wide variations in facility type, design, and operation. These two settings are: 1) a low-permeability sediment layer in the discharge zone location, and 2) a semi-arid climate and a thick unsaturated zone setting. Therefore, these two settings may offer the opportunity for waivers on liners and leachate collection systems.

As indicated earlier, the current feeling at EPA is to consider waivers on liners and leachate collectors but not to consider waivers on cover systems and closure requirements. Additional studies are planned by the Agency in 1984-1985 to further the analyses of location/facility factors. EPA is still several years away from specific changes in the regulations related to locational standards.

The third study for the Economic and Policy Analyses Branch is currently in the report-writing stage of a first phase analysis. Therefore, conclusions and findings of this work cannot be released at this time. However, it is possible for us to summarize the approach being taken and indicate the type of issues the Agency hopes to resolve through the studies.

This liner-location project has the objective of estimating the risk of exposure of human populations to various contaminants that would be released to the environment from regulated facilities. A generic modeling approach has been taken in which facilities are designed and operated in ways that would comply with regulations, and hydrogeologic settings would reflect conditions on actual regulated facilities. The risk analysis ultimately supports an economic analysis of hazardous waste facility, design, performance, and location standards.

Some of the more important issues being addressed in this study include:

- The level of risk reduction afforded by leachate collection and removal systems
- The level of risk reduction afforded by facility locations overlying non-aquifer materials
- Cost/benefits of synthetic versus clay liners
- Cost/benefits of banning selected wastes from land disposal.

OVERVIEW OF CURRENT FEDERAL REGULATIONS

The purpose of this section is to examine several technical issues concerning the land disposal options of landfills and land treatment units in the United States. A synopsis of the Federal regulations that control design and operation of these facilities is presented and is followed by a discussion of technical issues concerning compliance monitoring, closure and post-closure requirements, compatibility of wastes and construction materials, and the long-term containment feasibility of these facilities. Finally, a discussion is provided of the work currently being done concerning geologic location standards and how hydrogeologic conditions are being integrated with engineering design standards at these facilities.

This section focuses on the 40 CFR Part 264 Interim Final Regulations developed by the U.S. Environmental Protection Agency (July 26, 1983). Federal regulations have been evolving over the last few years and will continue to change as the land disposal technology develops. The compilation of a complete list of technical issues that the EPA is currently dealing with is beyond the scope of this project. Rather, a few key issues are discussed and evaluated in order to give an overview of current thinking on land disposal.

Federal regulations which control the use of hazardous waste materials have been developed by EPA in accordance with the Resource Conservation and Recovery Act (RCRA) of 1976. The Part 264 regulations were developed to respond to Section 3004 of Subtitle C of this action. The most current set of regulations was promulgated on July 26, 1982. These regulations rely on design and operation performance standards that are facility-specific, and on a ground-water protection standard which is applicable to all facilities.

According to this set of regulations, a "regulated unit" is a facility that treats, stores, or disposes of hazardous waste after the date of Janaury 26, 1983. Four types of facilities are included: landfills, surface impoundments, waste piles, and land treatment units. The discussion here focuses primarily on landfills and land treatment. However, it should be pointed cut that a waste pile that is closed by capping in a manner similar to closure of a landfill constitutes a facility that is essentially equivalent to an "above-ground engineered landfill." This optional design will be discussed in a later section.

The Part 264, regulations apply to both new and existing waste management facilities and distinguish between these units in appropriate circumstances. New landfills, land piles, and surface impoundments must generally be underlain by impermeable liners. New landfills and waste piles must also collect, remove, and treat liquids (leachate) that collect at the bottom of these facilities. The regulations provide for a waiver for the liners and leachate collection system where applicants can demonstrate that their wastes will never migrate to ground water or surface water. Any active portion of a facility that existed prior to January 26, 1983, also would be exempt from these requirements. However, both new and existing facilities would be subject to the following five areas of control: dispersal of waste material by the wind, control of run-on and run-off of surface water, capping of waste removal at closure, post-closure care and monitoring where wastes remain, and financial assurance for closure, post-closure care, and liability coverage.

The Part 264 ground-water protection requirements establish a three-stage program to detect, evaluate, and, if necessary, correct ground-water contamination. The first stage involves detection monitoring of ground water with wells located upgradient and downgradient of the boundary of the waste management area. If this monitoring provides evidence that leachate from the facilities has created a contaminant plume that has reached the waste boundary, the permittee enters the second stage - a compliance monitoring program which tracks the migration of the hazardous constituents in the ground water. Concentrations of the constituents are compared to a ground-water protection standard that is based on one of the following: 1) for any constituent, the background level in the ground water, 2) for any of the 14 constituents in the Interim Primary Drinking Water Regulations, the maximum concentration limits, or 3) an alternate concentration limit shown by the permittee to not create a significant human health or environmental hazard.

If the ground-water potection standard is violated, the third stage - corrective action - is activated. Corrective action, such as the removal of contaminated water or in-situ treatment of the constituents, must be performed until the ground-water standard is complied witn.

The regulations provide an option whereby permittees may comply with more stringent design and operating standards to obtain a waiver on these monitoring and response requirements. These standards include two bottom liners (instead of the single liner generally required) and a leak detection system between the liners (in addition to the leachate collection and removal system above the liners). If a leak is discovered, the leaking liner must be repaired or replaced, or the monitoring and response requirements become effective. Both the design and operating standards and the ground-water monitoring program will be controlled through the issuance of permits. In the case of the ground-water monitoring and response program, permit modifications may be required when there is a need to move from one stage of the program to the next.

Landfill Regulations

Subpart N of Part 264 contains the design and operating standards for landfills. These regulations have been supplemented by a guidance document prepared by EPA. The basic requirements for landfills are: 1) a liner to prevent migration of wastes from the landfill into the underlying ground water during the active life; 2) a leachate collection and removal system; 3) control of run-on and run-off; 4) capping the waste at closure and conducting post-closure care. An exemption from the ground-water protection requirements, discussed earlier, is provided for landfills that have double liners and a leak detection system.

EPA has placed certain restrictions on the types of waste that can be landfilled. The Agency is currently restricting the landfilling of ignitable and reactive wastes, bulk liquid wastes, and solid wastes that have not been crushed or packed properly prior to disposal. The Agency is currently studying the issue of banning selected industrial solvents from landfills.

A number of states have already taken legislative and regulatory action over the past three years. California has imposed land disposal restrictions which went into effect in June 1983 on certain levels of cyanide wastes, toxic metals, acid wastes, and PCBs. A ban on liquid and solid wastes containing certain levels of halogenated organic compounds will go into effect beginning in 1985. Other states that are active in this area include: New York, New Jersey, Illinois, Massachusetts, Missouri, Ohio, Minnesota, Rhode Island, and Wisconsin. The nature of these activities are shown in brief on Table 2. The EPA has recently initiated a program to explore whether certain wastes should be restricted from some or all type of land disposal, what the nature of the restriction should be, and what treatment and recycling alternatives exist for such wastes.

Table 2. Summary of State Activities for Restricting Land Disposal of Hazardous Wastes

State	Legistlative Action	Report Required by Legislature	Regulatory Action Proposed	Regulatory Action Draft	Regulatory Action Final
California	X	X			X
Illinois	X				
Massachusetts					X
Minnesota	X	X	X		
Missouri					X
New York	X	X			
Ohio			X		
Rhode Island					X
Wisconsin	X	X		X	

Source: USEPA 40 CFR, Chapter 1, February 15, 1984.

The Part 264 Regulations have been formulated with the goal of eliminating the escape of leachate from landfills to the extent practical for all time. EPA believes that containment can be achieved during the operating life of most facilities in the absence of damage to the containment system. In the long run, it acknowledges that minimizing leachate formation and limiting leakage is the best that current technology can achieve.

Where practical, the liner system must be constructed wholly within the unsaturated zone above the seasonal high water table. The Agency agrees with the concept that certain hydrogeologic settings and accomodating designs will permit installation of liners into saturated materials. However, the Agency is still studying this issue and has yet to provide any technical guidance in this area. This issue will be discussed further in the section on location standards.

From a technical point of view, EPA considers the synthetic liners to be essential because they can provide a high level of confidence of containment during the active life of a facility. The clay liners are seen as only slowing down the transport of contaminants; however, EPA considers them to have a greater potential life span than the synthetic liners. The Agency believes the clay liners are valuable as a backup to synthetic liners and suggests that they be used as an extra measure of protection in all cases. EPA realizes that there is disagreement as to the relative effectiveness of various liner types and is currently conducting several research projects concerning the relative efficiency of these liners, effective life spans, analysis of ways in which these liners fail, and cost/

benefits to be realized along with the risks posed by various liner designs.

It is worth noting here that permit applications for new facilities are being carefully reviewed by EPA for all aspects of design. In the area of liner design, the Agency is concerned about the methods used by the applicant for demonstrating that liner specifications will be met. Issue areas include the disparity between laboratory and field permeability determinations of clay liners, the modeling methodology used to calculate the thickness of the clay liner when a waiver is desired on the synthetic liner, and adequate demonstration of waste/liner chemical compatability testing.

The regulations require that the leachate detection, collection, and removal system be capable of limiting leachate depth on the bottom of the landfill to a maximum of 0.3 meters, that it be constructed of materials that are chemically compatible with the wastes, and that it can withstand pressures and disturbances from the weight of the overburden wastes, cover materials, and equipment. The regulations do not require monitoring of the height of leachate above the bottom of the landfill, only that the applicant demonstrate that the design of the system will insure a leachate depth of one foot or less, except perhaps temporarily during severe storms.

The landfill guidance document recommends design criteria for meeting the above standards. Design criteria include grading of granular material to prevent clogging, minimum permeabilities of the drainage layer, minimum slopes of drainage layers and collection piping, drainage tile diameter and spacing, and chemical composition of drainage pipe. It is also recommended that a woven geotextile fiber be used above the leak detection system to prevent movement of waste material into the system. An unresolved issue in the performance of the leachate collection system is the clogging of the system due to biological activity. This phenomenon has been documented by one EPA contractor at an existing landfill. As yet, the Agency has not provided any guidance for the avoidance of biological clogging.

The final cover on a landfill must be designed to minimize infiltration of precipitation and must be no more permeable than the liner system. It must be designed to promote drainage of surface water while minimizing erosion. It must be vegetated and operate with a minimum amount of maintenance. Also, it must be designed so that settling and subsidence of the wastes are accommodated to minimize the potential for disruption of the final cover.

In cases where landfills have multiple cells stacked vertically, an interim cover is placed over each cell and the final cover is not emplaced until the final lift is completed. As a minimum, the cap must consist of the following three layers: 1) a vegetated top layer; 2) a middle drainage layer to remove surface water infiltrating through the vegetated layer; and 3) a low permeability bottom layer. The liner guidance document provides acceptable specification for the cover material including: 1) thicknesses of layers, 2) minimum slopes on the cover; 3) permeabilities of materials; 4) suitable vegetation to be planted on top of the cover.

The Agency believes that a three-layer final cover will adequately minimize infiltration and prevent the so called "bathtub effect" from occurring within the landfill. The bathtub effet occurs when leakage through the cover exceed leakage through the bottom liner. The landfill starts to fill up with leachate until it leaks out near the edge of the landfill. This phenomenon has been documented at a number of existing sites for both chemical wastes and NRC regulated low-level nuclear wastes.

The bathtub effect generally results from settlement of wastes and the subsequent fracturing of cover materials which provides avenues through which surface water may enter the landfil. An unresolved technical issue, then, is how to engineer the wastes to prevent settlement caused by the natural processes of chemical and physical alteration of the wastes. A potential solution to this problem may be found in the location standards to be discussed later. It may be possible to combine engineering and locational factors to ensure that even if covers fail, the bathtub effect will not occur.

Land Treatment Regulations

Because EPA is concerned about the uncontrolled dumping of wastes onto land, it is controlling the types of wastes, operational procedures, and compliance monitoring. The Agency believes that land treatment should generally be confined to degradable organic wastes. However, it also believes that smaller inorganic or persistant organic fractions of these wastes can also be effectively treated. For example, heavy metals and persistant organics are either unaffected, or only slowly affected, by the treatment mechanisms, but can be immobilized by chemical reactions such as precipitation, adsorption, and ion exchange.

As mentioned above, the waste application rate, control on pH, and other operational procedures, must be clearly documented and tested by the permit applicant. Waste and site-specific operations may include proper tilling of soils, maintenance of soil nutrients for microbial populations, and management of the water content in the treatment zone.

A land treatment permit requires a clear definition of the treatment zone, the portion of the unsaturated zone that will degrade, transform, or immobilize the constituents. The regulations currently limit the thickness of this zone to 1.5 m (5 ft). The regulations also require that the bottom of the zone be no closer than one meter to the high seasonal water table.

Another major part of the treatment program is to establish an unsaturated zone monitoring program within the interval between the bottom of the treatment zone and the top of the saturated zone. The purpose of the monitoring is to assist in "fine tuning" the treatment program rather than triggering the corrective action program which is reserved for ground-water monitoring.

Both soil-core and soil-pore liquid monitoring are required with the intent that each should complement the other. EPA believes that soil-core monitoring will provide control on slower-moving constituents such as heavy metals, whereas soil-pore monitoring will provide control on fast-moving constituents such as volatile organics. Like the ground-water monitoring program, background conditions must be defined so that statistical procedures can be used to determine if hazardous constituents are migrating out of the treatment zone.

There are two major issues concerning unsaturated zone monitoring. The first is the use of lysimeters for the soil-pore water sampling. Because of limitations of this sampling device in certain soils, and because many persons are unfamiliar with the installation and use of lysimeters, both practical and theoretical issues have been raised. EPA is currently reviewing the use of lysimeters for this purpose and has not yet resolved the issue.

The other concerns uncertainties in the application of the statistical tests. Because of the relatively small number of samples and constituents being monitored, the probability of experimental error is high. Although the Student's T-test protocol has been used for both saturated and unsaturated zone monitoring, it is currently under review by the Agency. EPA intends to further analyze the appropriateness of other statistical procedures for interpreting data in both zones.

In order to obtain a permit for a land treatment facility, the applicant must demonstrate that the proposed operating procedures can degrade, transform, or immobilize hazardous constituents in the proposed wastes. The treatment demonstration can be accomplished using information from published sources, laboratory studies, field studies, or actual facility operating experience (i.e., monitoring results). Successful demonstrations will generally involve data obtained from several of the above sources.

At a minimum, the following unit-specific conditions must be simulated: 1) characteristic of the waste; 2) depth and characteristics of the treatment zone; 3) geometry of the treatment zone; 4) climate of the region; and 5) operating practices. Specific guidance regarding the necessary elements of the treatment demonstration is provided in the land treatment guidance document.

In some cases, food-chain crops may be grown on land treatment facilities. This practice is of a concern to EPA which has placed restrictions on the growth of food-chain crops. EPA believes, however, that food-chain crops can safely be grown when standards are met. The standards require that a permittee comply with two criteria. First, he must show that hazardous contstituents will not occur in greater concentrations in plants grown on the unit than in plants grown in untreated soils under similar conditions in the region. Second, if cadmium is present, he must comply with certain specified practices that are designed to limit entry of cadmium into the food chain.

According to the regulations, the operator of a land treatment facility must continue operating practices for some period of time after the last waste is applied to the land surface. This would include practices such as tilling of the soil, control of soil pH and moisture content, and fertilization. During this period, unsaturated zone monitoring must be performed until sufficient treatment has occurred. At the end of this period, the operator has the option of removing contaminated soils or providing a vegetative cover over the site to minimize erosion and to aid in the treatment of hazardous constituents.

During the post-closure care period, the operator must continue many of the activities required during the active life and closure period. These include control of wind dispersal, maintenance of run-on and run-off, and food-chain crop restrictions. The operator must also continue soil-core monitoring but may suspend soil-pore monitoring 90 days after the date of the last waste application. The operator may also be required to apply certain chemicals to the land surface to maintain pH of the treatment zone but will probably not be required to till the soil since this would destroy the vegetated cover. The operator can obtain an exemption from both unsaturated zone and ground-water monitoring during the post-closure care period if he can successfully demostrate that one of the following situations occurs: 1) hazardous constituents are no longer present in the treatment zone at statistically significant amounts; 2) no hazardous constituents have migrated below the treatment zone during the active life of the unit.

Location Standards

As used in this report, the term "location standard" is used to mean location-dependent hydrogeologic conditions that either control siting, or control design and operating requirements at new facilities. This section summarizes the few location standards in Part 264.

Location standards in Part 264 are limited primarily to considerations of seismic risk and flooding potential. New facilities cannot be located within 61 m (200 ft) of a fault that has had movement on it within the last 11,000 years (Holocene time). Facilities that are located on a 100-year flood plain must be designed to prevent washout of wastes by a 100-year flood, unless it can be demonstrated that wastes can be removed safely before flood waters reach the facility, or that no adverse effects to human health or the environment will result if washout occurs.

The regulations also deal with location standards by permitting a waiver for the liner and leachate collection and removal requirements when the applicant can demonstrate that the use of alternate design and operating practices, in combination with location and waste characteristics, will prevent the migration of any hazardous-waste constituents into the ground water or surface water.

An example of a situation for which this exemption may be appropriate is one where: 1) a large and unsaturated zone below the unit is composed of materials that are capable of attenuating any hazardous constituents in the leachate before it reaches the ground water, 2) the unit is located in an arid region in which precipitation does not recharge ground water, and 3) the unit handles only a very small quantity of waste. Even though an applicant may obtain a waiver for liner and leachate collection systems, EPA will not grant a waiver for the closure provisions in the regulations.

Another waiver from the design and operating requirements considered by EPA involves facilities located over aquifers that contain water that is not suitable for drinking. However, because of the Agency's concern about contaminant migration through these poor aquifers to useable aquifers or to surface-water bodies, it has been hesitant to offer these waivers. This is an issue that the Agency has not had time to fully evaluate and is still unresolved.

Comparison of New Jersey and Federal Regulations

The State of New Jersey's proposed regulations concerning hazardous discharges of pollutants to the ground water or onto land from which the pollutants may enter the ground water may be the strictest state regulations governing landfills and land treatment. These regulations, whose intent are to allow the state to proceed with obtaining authorization to administer the Federal Resource Conservation and Recovery Act of 1976 (RCRA), will shortly go into effect. The New Jersey regulations exceed the RCRA regulations in requirements for design and monitoring. Below a brief summary is given on how New Jersey's proposed regulations for landfill and land treatment differ from existing Federal regulations.

Landfills

- New Jersey requires all hazardous waste landfills (new and existing) to have a double liner system whereas the Federal government requires only a single liner.
- New Jersey requires all hazardous waste landfills to have a ground-water monitoring system, but the Federal regulations allow an exemption when the landfill is double lined.
- New Jersey requires liners of greater thickness than specified in the RCRA Guidance Document. Specifically for new landfills the primary (upper) liner must be of synthetic material at least 40 mils (0.04 inches) thick with a maximum hydraulic conductivity of 1×10^{-7} cm/sec. The secondary (lower) liner must consist of soil at least 1.5 meters thick or

synthetic material at least 40 mils thick with the same maximum permeability as the upper liner.

- New Jersey requires a 0.3 meter separation between the double liners to provide protection for the leak detection system required but the Federal government does not require a leak detection system unless there is a double liner system and a resulting exemption from the ground-water monitoring system.

- New Jersey requires all hazardous waste landfills, without exception, to have double liners and a leachate collection and removal system, whereas the Federal regulations allow for an exemption from the federally required single liner and leachate collection and removal requirements.

- New Jersey requires gas monitoring but the RCRA regulations do not address this concern.

Land Treatment

- New Jersey requires all hazardous waste land treatment units to have a ground-water monitoring system whereas the RCRA regulations provide for an exemption under certain circumstances.

FUTURE OF LANDFILLS AND LAND TREATMENT

Landfilling and land treatment are waste disposal technologies that have developed rapidly over the last two decades. Landfilling is currently in wide use in the U.S. while land treatment is popular only in certain regions and for certain types of wastes. Landfilling has come a long way from the early days in which wastes were indiscriminantly disposed of in poorly regulated dumps. Similarly, land treatment has blossomed, especially for handling petroleum refinery waste and sewage treatment sludges. Although these are currently popular, it is reasonable to question whether they will continue to be popular in light of the rising cost of land disposal and the growing opposition against all new facilities within the community at large. In this section, we will attempt to speculate about future trends in these two waste-disposal technologies.

Some writers have suggested that landfills of the future will, or should, be installed above ground. Proponents of this idea point out that when constructed over sloped double liners, above-ground landfills would offer several major advantages over below-ground landfills. Much of the technololgy already developed for underground landfills, including double liners, leachate collection systems, waste stabilization, and covers could readily be adapted for above-ground landfills. It is argued that continuous gravitational leachate removal would potentially reduce the risk fo contaminating underlying ground water. Also, while underground landfill leachate collection systems are inaccessible and unrepairable, it is argued that above-ground facilities would be much more accessible and repairable.

While there are some good points to be made in favor of above-ground landfills, it is still in the conceptual stage and has not been properly field tested. In one sense, the current regulations for waste piles are not significantly different from the concept of an above-ground landfill. For this reason, the collective experience of waste generators with new waste piles should provide a partial test for the concept of above-ground landfills.

There is little doubt that the high cost of designing and operating a landfill that will comply with regulations creates an incentive to find other ways to deal with the waste. Technologies like recycling, pre-treatment, and incineration are becoming more economically attractive and may serve to reduce the number of landfills in the future. However, even with treatment there will always be a certain amount of treated residues that will have to be landfilled.

Land treatment systems offer a potentially cost-effective, relatively low-risk, and environmentally acceptable method for the management of some hazardous waste. The continued interest in the application of this technology is evidence that it may be acceptable to both industry, government, and the engineering community. Sites located on the property of an industry, near the source of the waste, tend to meet less resistance from local agencies and the public than do centralized sites operated by a public agency or by a consortium of industries. Approval for these centralized facilities has become very difficult and generally requires a higher level of supporting data and predictive modeling of failure scenarios.

MINED SPACE

The use of underground space for waste disposal had been extensively studied both in the United States and abroad. Underground space has also been considered and used for other applications such as storage of petroleum products, alternative energy systems, and storage of critical records data.

In the United States, the largest body of research related to underground space has been developed for high-level radioactive wastes. This work forcuses on disposal in dedicated mined-space or space created specifically for disposal purposes. The primary target formation for these activities are salt deposits (both bedded and domal) and the northern United States crystalline rock formations.

Experience with the creation of dedicated underground space for hazardous waste storage and disposal is very limited, primarily due to economic and political constraints. Use of existing mines or abandoned mines for hazardous waste storage and disposal is also limited. Based on a limited literature search and personal contacts made as part of this study, there are no documented cases of the disposal of hazardous wastes in mined underground space in the U.S. However, there have been several planned disposal sites that have not yet been approved or implemented.

In general, the concept of waste disposal in mines usually involves the use of drummed wastes that can be stored and retrieved if necessary. An exception to this is a waste disposal activity in an abandoned coal mine in the United Kingdom where liquid wastes are essentially dumped in the mine (NATO, 1977, 1981). Unlike land disposal, the emphasis is on storage in accessible space, not on "perpetual seals or covers." Under most scenarios, mined storage areas would be open in order to monitor for leaking containers and replacement if necessary.

Radioactive Waste Experience

The U.S. experience in high-level radioactive waste disposal is focused on underground storage in salt deposits and crystalline rock formations. Although extensive resources have been expended on research, including conceptual design and siting, actual construction of the first repository is not to be done until the 1990's. Candidate locations for the first repository include basalts and tuffs in the western U.S. and salt formations in the southern and southwestern U.S. These areas are indicated on Figures 1 and 2 and include both bedded and domal salt deposits. Nine sites in these areas are under consideration for development. The list will be narrowed to three in the mid-1980's and among these one will be selected for development in the 1990's.

Currently, the salt deposits of the north central and northeastern U.S. are low on the priority list for repositories, mainly due to the political influences and the availability of other salt deposits in less populated areas. The Salinas Basin, however, has been extensively studied and has been considered an important disposal alternative for radioactive waste (Geraghty & Miller, Inc., 1979; Empson, 1963, 1966; National Academy of Science, 1970; Battelle, 1983; Oak Ridge National Lab, 1966). In addition,

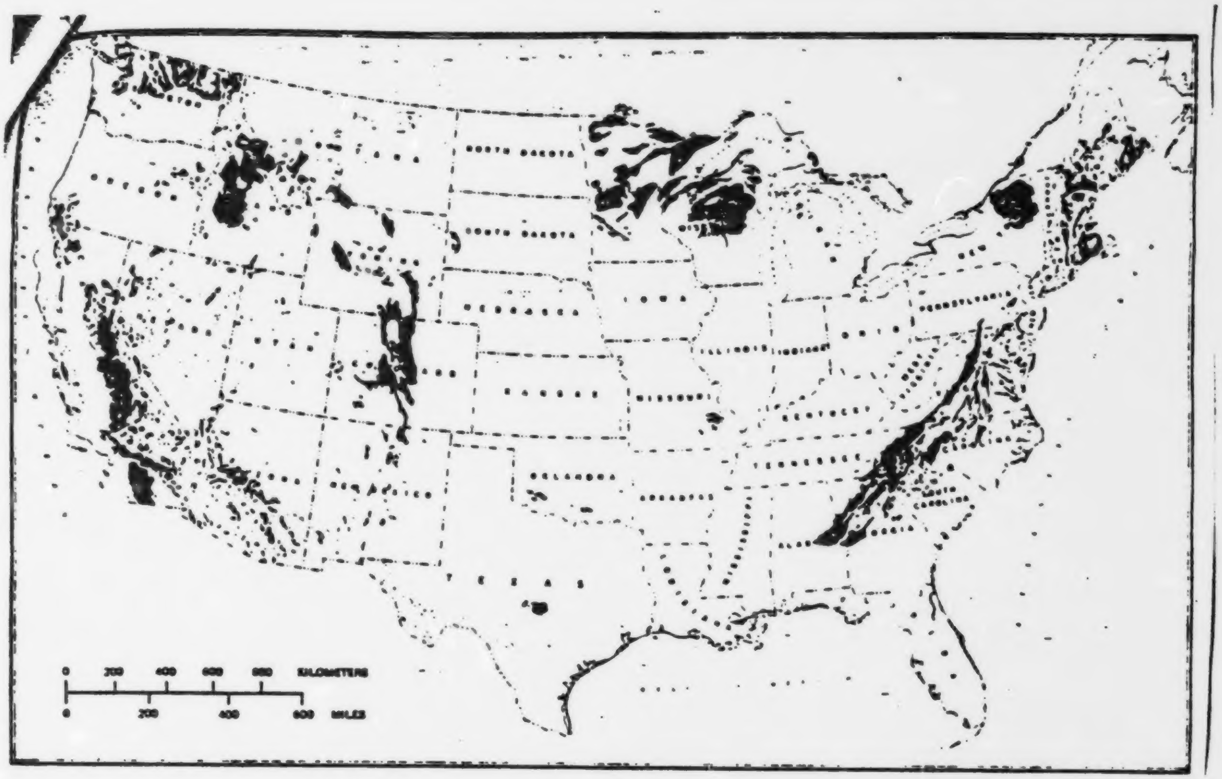
T E X A S
0 200 400 600 800 KILOMETERS
0 200 400 600 MILES

Figure 1. Distribution of Exposed Crystalline Igneous Rocks (black) in the Conterminous United States (from Bedinger and Sargent, 1981).

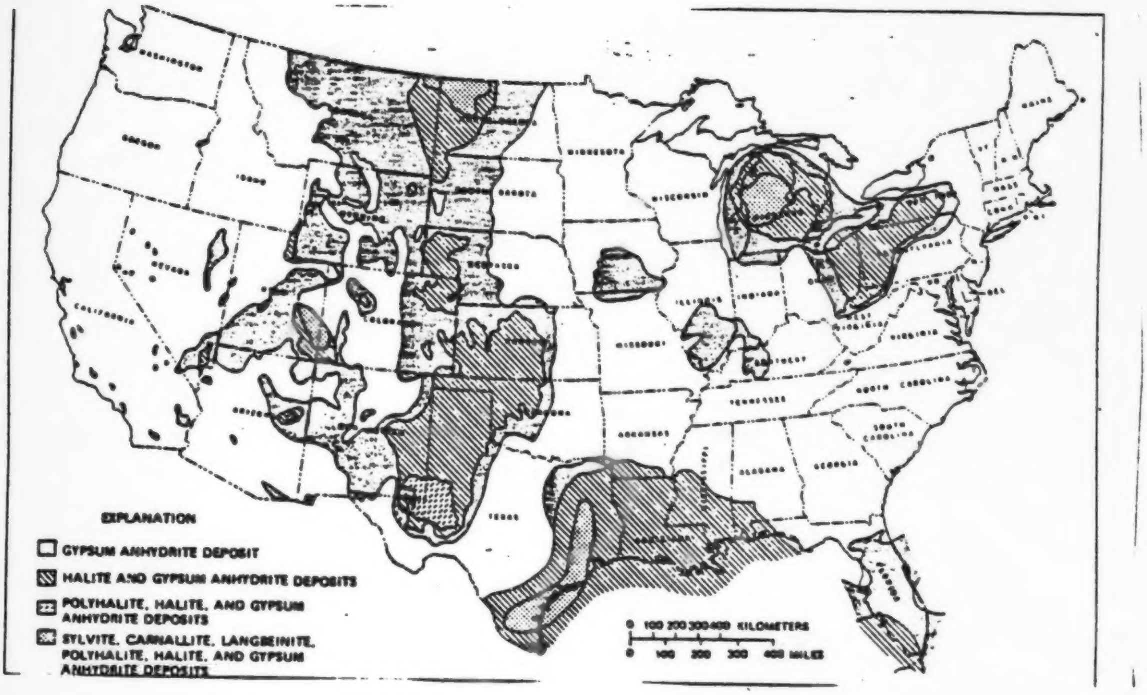
EXPLANATION
GYPSUM ANHYDRITE DEPOSIT
HALITE AND GYPSUM ANHYDRITE DEPOSITS
POLYHALITE, HALITE, AND GYPSUM ANHYDRITE DEPOSITS
SYLVITE, CARNALLITE, LANGBEINITE, POLYHALITE, HALITE, AND GYPSUM ANHYDRITE DEPOSITS
0 100 200 300 400 KILOMETERS
0 100 200 300 400 MILES

Figure 2. Marine Evaporite Deposits of the United States (from Bedinger and Sargent, 1981).

the Salinas salt deposits have also been developed for hydrocarbon storage using solution mining techniques (Kreidler, 1966).

The U.S. is concurrently planning a second repository for development three to four years after the initial facility. This is to be sited in the crystalline rock formations somewhere in the northcentral and northeastern U.S. (Minnesota, Michigan, New England States, etc.). The DOE operations office in Chicago is responsible for the crystalline rock program where resource characterization and conceptual design programs are funded.

Key criteria used in evaluating host rock formations in the United States radioactive waste storage program include (Bedinger and Sargent, 1981; National Academy of Sciences, 1978; National Research Council, 1983):

- Cavern stability
- Mineability
- Fracture density
- Permeability
- Dimensions and geometry
- Homogeniety
- Sorption capacity
- Thermal conductivity
- Geochemical compatability
- Adjacent ground-water flow system

It is felt that formations with favorable storage criteria can be found in the northeastern and north-central U.S. A study of the New England States performed to locate suitable locations for excavation of large caverns for alternative energy systems reviewed over 1,180 rock formations. Approximately 90 formations were considered to have favorable characteristics for large cavern development (Farquhar, 1977) most of those being uniform masses of relatively undeformed granite.

Other formations, such as shale, have been considered for radioactive waste disposal in the United States (Gonzales and Johnson, n.d.). These may represent potential future storage areas for hazardous wastes.

Hazardous Waste Experience

Storage/disposal of hazardous wastes in previously worked (abandoned), active, or newly developed mines has been considered in the United States and abroad, although actual applications are limited. In particular, a detailed study of underground disposal in these settings was developed by NATO's Committee on the Challenges of Modern Society (1977). Advantages and disadvantages of different strategies are discussed and summarized in the next section.

The most notable application of mine disposal presented in the literature is the underground waste disposal facility at Herfa-Neurode in Germany. This facility, in operation since 1972, is located in an abandoned portion of a salt mine in the Werra-Fulda Salt Basin.

In the United States, two examples of proposal mine disposal of hazardous waste were discovered. In the State of Minnesota, the Waste Management Board conducted a siting study to locate crystalline rock deposits for dedicated hazardous waste storage and disposal. The project is currently inactive and stalled at the conceptual design/siting stage.

The second case involved a large manufacturer, PPG Industries, Inc., who investigated the use of an abandoned limestone mine for waste storage and disposal in Ohio. A conceptual design was developed, but the concept was not approved due to political opposition. These examples are described in the following pages.

Summary of Case Histories

Underground Disposal at Herfa-Neurode

The Herfa-Neurode facility, an underground hazardous waste disposal facility, has been developed near the town of Bad Hensfeld, West Germany, in an abandoned section of the Wintershall Salt Mine. The mine, developed in the northern section of the Warra-Fulda Salt Basin, lies approximately 700 meters deep in a deposit between 250-300 meters thick. It is covered with low-permeability clay and shale layers. Details of the local geology, mine design and operation are described in Johnsson (1983) and NATO (1977).

The mining method used in the original salt extraction operation was a conventional room and pillar technique. Several hundred thousand cubic meters of salt are formed in a three-meter thick layer. The same salt formation is being actively mined about 10 kilometers away at a rate of about two million cubic meters annually.

Mine stability is very good with insignificant ground pressures and creep. Stripping ratios of 60-70 percent have been performed with no roof collapse and gallaries are approximately 10 meters wide. As the storage area is in the center of the salt deposit, surrounding ground water is protected by about 150 meters of salt.

More than 1,000 different wastes are disposed in the facility, each with detailed manifests of quality and quantity. Wastes are generally solids or pastes placed in containers and stored vertically on pallets. Waste of different characteristics are isolated in different areas of the mine. Mine operation is designed such that wastes can be retrieved at the request of the producer in the event that a future market value develops. Details of system operation and management measures are presented in Johnsson (1983). From 1972 to 1981, 245,000 metric tons of waste were stored in the mine, including both domestic and foreign wastes, all cataloged to allow location and removal.

The most commonly stored materials include treatment salts, residues from chlorination of hydrocarbons, pesticide wastes, and wastes from the pharmaceuticals industry. For safety reasons with regard to the underground operation, the following restrictions on wastes are imposed:

- No wastes are permitted which might develop under the prevailing conditions underground a gas-air mixture which is explosive, ignitable, toxic or otherwise hazardous for the operation.
- Wastes which might have a tendency of self-ignition or otherwise instability are prohibited.
- No liquid wastes are permitted. If need be, and if other disposal methods are not available, those wastes must be transformed by appropriate methods mutually agreed upon in at least semi-solid consistency. In any case, it must be warranted that if damage to the packaging occurs, no free flowing liquids can escape and contaminate the surroundings.
- Wastes are not permitted that might react with the surrounding salt in such a way that the operation can be endangered.
- Wastes that may possibly react with each other are disposed at sufficient distance so that they cannot come in contact with each other. This is possible due to the spacious extensions of the available section.

- No wastes coming under the special regulations for radioactive materials are disposed at Herfa-Neurode.

Disposal Feasibility Study: Minnesota, U.S.A.

The Hazardous Waste Management Board of the State of Minnesota funded a study to determine the cost and technical feasibility of hazardous waste disposal in dedicated mined space. The study, focusing on locating a repository in crystalline rock areas, is described in detail by Brady et al. (1982). Currently, little work has been done on the prospective sites due to political opposition to the waste disposal alternative. As a result, the primary output of this effort is a summary of four possible sites in northern Minnesota. Preliminary drilling/coring results indicated very low fracture densities, a sign of potentially good hydrogeologic conditions.

Site selection of a possible repository site was based on regional geology and hydrogeology. The geological criteria for site selection includes adequate depth, thickness, and lateral extent of the host rock mass, adequate strength and deformation characteristics, degree of uplift or subsidence, and absence of faults. The hydrogeological criteria include low-mass permeability, low porosity and water content, low ground-water gradient and adequate distance from utilization or discharge points.

Areal photographs were used to determine large-scale regional geological fractures, while drilling and geophysical testing were used to determine small-scale features.

Based on historical experience within the mining and underground construction industries, two designs of a repository were presented, with a capacity of 9,000 and 90,000 metric tons per year respectively for 20 years of operation. The repositories would be constructed at selected depths of 300 meters, based on several comparative studies of the optimum depth for safe operation, and would consist of a single horizon of a series of parallel disposal galleries and haulageways. Each gallery would allow for approximately 17 waste packages per foot of disposal gallery. Figure 3 presents the design of the 9,000 metric ton-per-year capacity repository. The estimated time and cost for each stage of development and operation for this repository were also calculated. Such a facility would be developed in about five years at an estimated total cost of 18-56 million dollars with a $1.5 million/year operation cost.

Disposal in Previously Mined Space: PPG, Norton, Ohio

A technical and economic feasibility study was performed for PPG Industries, Inc., for a hazardous waste disposal facility in a limestone mine (Norton Mine). The project has been cancelled due to political constraints; however, engineering design work prepared in the proposal phase indicates key design characteristics.

The preliminary investigation determined the feasibility of converting an abandoned limestone mine located in Norton, Ohio, into an underground hazardous waste storage facility. According to this investigation, the geological and hydrogeological characteristics of the site make it an ideal location for an underground hazardous waste disposal facility. The Norton

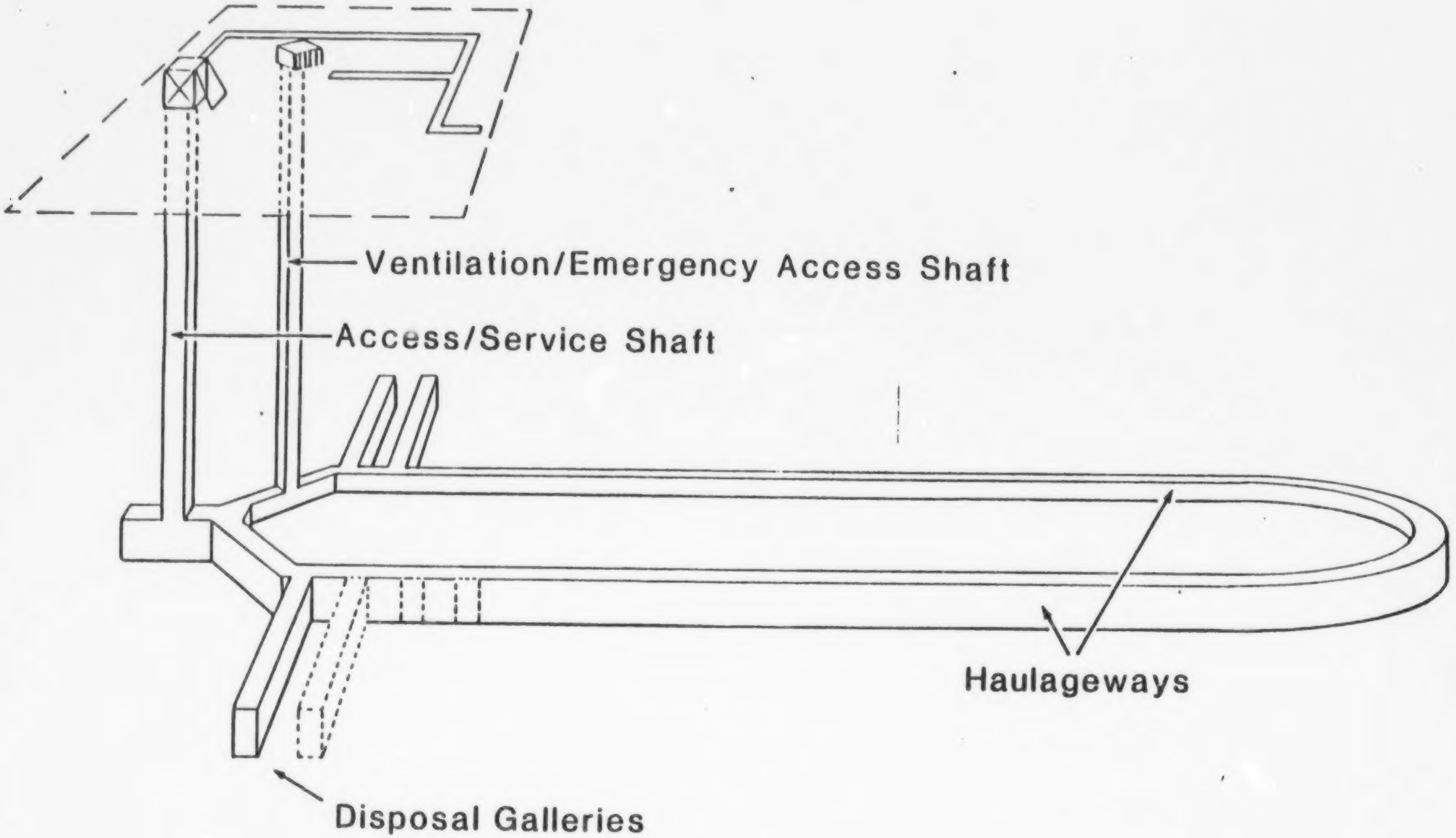
Ventilation/Emergency Access Shaft
Access/Service Shaft
Haulageways
Disposal Galleries

Fig. 3. Conceptual design for 9,000 TPY repository (Brady et al, 1982).

mine is located in an area where seismic activity is judged to be minimal. A cross section of the mine is presented in Figure 4. The mine is at a depth in excess of 670 meters below land surface in the Columbus limestone and is separated form land surface by 457 meters of low-permeability shale. As a result the mine is generally dry.

The mine is 14 meters high and more than 1.6 kilometers across with rooms that are 10 meters wide. The Columbus limestone is considered to be capable of limiting the movement of contaminants into the surrounding geologic formations. Also, ground water below the mine is salty.

As of 1981, PPG Industries, Inc., proposed the use of the Norton mine for the disposal of hazardous wastes from PPG plants as well as other sources. A total amount of approximately 45,000 metric tons of hazardous wastes per year was the design capacity. Proposed waste types included those containing asbestos, lead, mercury, chromium, copper, and other heavy metals, solid residues form the production of chlorinated benzenes, and materials from steel, plating, metal making, and chemical industries.

Safety and regulatory measures to be observed at the facility precluded materials which have a high vapor pressure. The wastes would be transported and stored in locked drums. A careful inspection of the arriving material would be done to insure that the shipment was intact and properly manifested. A statistical sampling would be done to assure the identity of the shipment. Once screened, the wastes would be stored in the mine according to an established location plan. Once a room was filled with waste, it would be sealed off with a concrete cinder block wall.

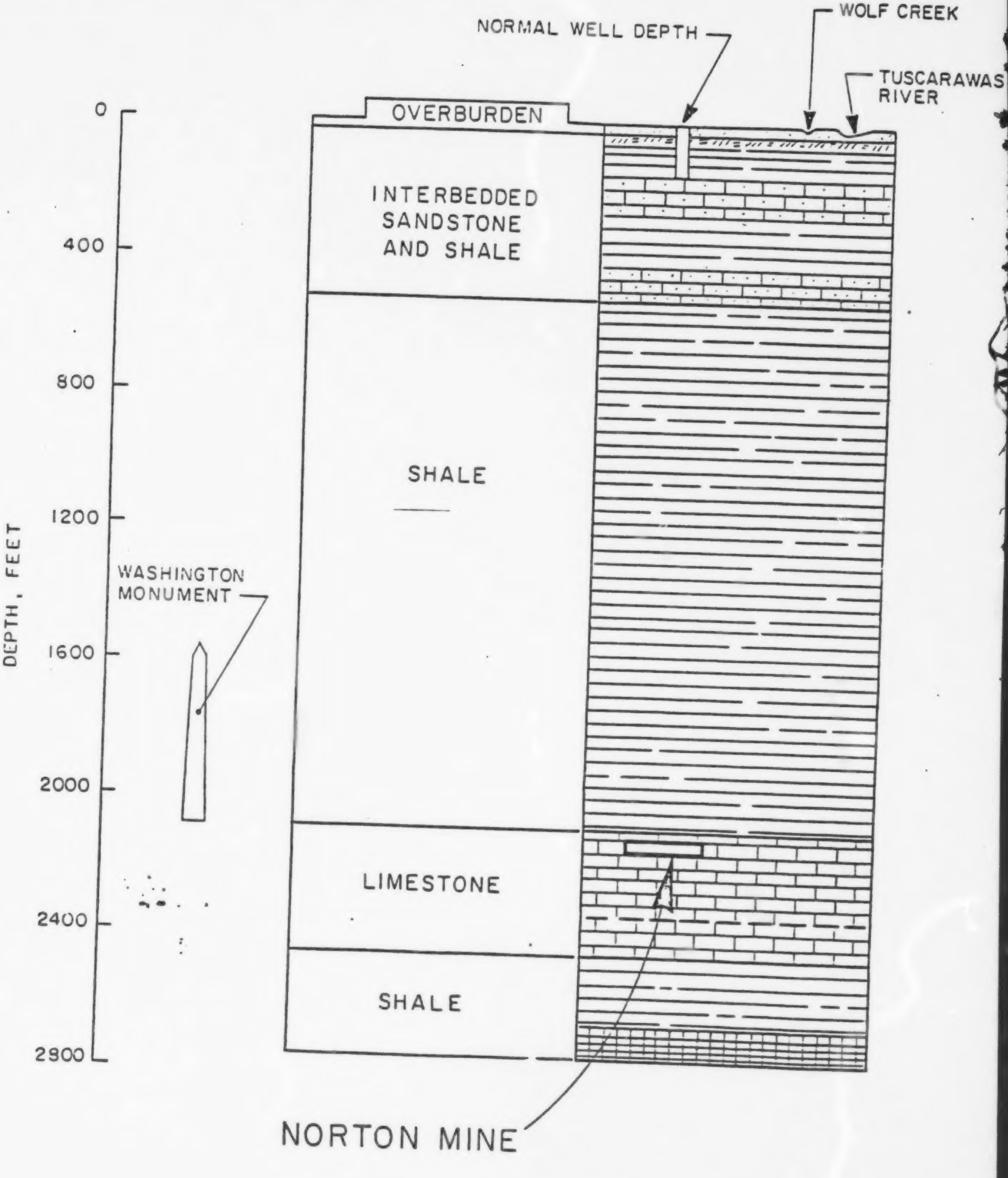
NORMAL WELL DEPTH
WOLF CREEK
TUSCARAWAS RIVER
OVERBURDEN
INTERBEDDED SANDSTONE AND SHALE
SHALE
LIMESTONE
SHALE
WASHINGTON MONUMENT
DEPTH, FEET
0
400
800
1200
1600
2000
2400
2800
NORTON MINE

FIGURE 4

GEOLOGIC COLUMN OF NORTON MINE

Key Techncial Issues and Constraints

The feasibility of developing underground mined space for hazardous waste storage/disposal is dependent on a range of engineering design, geological, and economic/institutional factors. Resolution of each of these areas is partially dependent on the stage of mine development (active, abandoned, or new) and whether the mined space will be developed specifically for disposal activities.

Geological/hydrologic and design conditions related to abandoned or activie mines (with the exception of conventional salt mines) are not necessarily ideal for waste storage/disposal. Mineral mines are generally oriented around an ore body where "dryness" is a less important criteria compared to overburden thickness and size of the mineral deposit.

Extensive mine dewatering systems are often associated with energy and mineral mines. Dewatering problems are often solved by pressure grouting techniques, which are useful over the life of an average mine, but are highly suspect over the lifespan of a waste storage/disposal project (hundreds to possibly thousands of years). Basic mine design, as it is tailored to ore body geometry, is likely not to result in totally level areas with large rooms and high ceilings.

Most applications designed for underground space in crystalline rock involve storage of non-containerized, bulk liquids or gases, where leakage must be minimized, not totally prevented. Therefore, applicability of these designs to hazardous waste disposal will be limited to "ideal" host rock formations.

Important advantages and disadvantages of mine storage/disposal are related to the phase of mine development. In an active mine, equipment and manpower are readily available as well as workable power and access infrastructure. Additional space can also be created, possibly with design requirements being met for storage/disposal. Unfortunately, due to safety constraints, waste handling must be isolated from activity mined areas. This constraint is relaxed in an abandoned mine as separation is no longer necessary and existing shafts can be used, thereby reducing mine conversion costs. This advantage is countered by the likely replacment of access and power infrastructure, extensive cleaning and conditioning and extreme space limitations in smaller mines.

Many of the limitations of active or abandoned mines can be eliminated through the concept of parallel mining operations for profitable product development and creation of storage/disposal space. Sequential development of storage space and product recovery can allow dual use of infrastructure. Although initial product recovery costs would be higher in order to accommodate long-term cavern stability and geometry requirements for waste storage/disposal, revenue from the activity could subsidize the mine design requirements. Constraints to this approach include possible inefficient exploitation of high quality ore bodies or creation of large volumes of waste from a low-quality ore body (the waste would ordinarily be disposed in the mined area). The NATO study team concluded (NATO, 1977) that abandoned mines overall are the most likely candidates for waste disposal based on economic and technical criteria.

Engineering Design

Design specifications for either previously mined or dedicated mined space include mine dimensions/configuration, mining method and mine location. Dedicated mined space can be designed to fit the specific requirements for waste management. Depending upon the design of existing mines (dimension and other mine conditions), existing space may or may not be adaptable to disposal design requirements.

The selected mine dimensions/configuration is critical in storage/ disposal applications. In particular, the design must assure long-term ceiling and wall stability while allowing for large enough space for waste compartmentalization. Ceiling height should be at least two meters to allow for passage of large vehicles and possible stacking of waste containers. Shaft entrances should be in a relatively accessible location, allowing year-round service and safe transport.

Mine design characteristics include parallel ventilation shafts for prevention of accidental accumulation of toxic gases. Also, single layer mine designs are preferred as multiple layers could be more open to roof instability and collapse. Selected mine mineral/pillar ratios are also related to material type and rock mechanics and must be designed for long term stability.

Mine depths suggested in the literature (NATO, 1977) should range from 100-900 meters. The shallower the formations, the more prone the area is to ground-water infiltration. In crystalline rock areas, the fracture density, or degree of secondary permeability, should decrease with depth. At greater depths, however, overburden pressure becomes high and access cost increases. These values are crude estimates; actual depth limits will also depend on overburden characteristics, host rock formation geometry and cost.

Other design considerations that are easily adaptable to most existing mine environments include: multiple shafts (fully cased and cemented to isolate any aquifers), decontamination response capability, multiple power sources, and enviornmental monitoring. Specifics of mine design and design criteria in salt formations are described in the radioactive waste disposal literature (National Research Council, 1978; National Academy of Sciences, 1970; ORNL, Nd; Empsom, et al., 1966). The Empson report specifically includes salt mine design characteristics for a proposed high level radioactive waste disposal site.

Geology

In general, storage/disposal of wastes, including high-level radioactive wastes, is considered satisfactory in dedicated domal and bedded salt deposits (National Academy of Sciences, 1970) and selected crystalline rock formations.

Numerous geological criteria must be addressed to determine the feasibility of safe subsurface disposal. Geological siting criteria are outlined in a number of documents, including the National Research Council (1978). This data shall be collected from previous mining operations and subsurface exploration, and will require additional field investigations. Some of the major geologic, hydrogeologic, and geotechnical items required include:

- Lateral extent and homgeneity of subsurface units
- Dimensions and changes of formation facies
- Orientation, persistence and spacing of fractures, joints, and foliation
- Location and composition of mineral filling of fractures, joints, and shear planes
- Composition of rock matrix and chemical interaction with waste type
- Presence of oxidizing minerals
- Regional and local tectonic activity
- Susceptibility of host rock to deformation from mining/blasting operations

Salt deposits, according to the NATO study (1977), appear to be the best environment for underground storage and disposal. Their rating is based on extensive geologic criteria including dryness/permeability, isolation, stability/structure, reactivity and homogeneity, seismicity, capacity, and geometry. Advantages of salt deposits in the U.S.A. include:

- Salt formations exist in tectonically stable areas which can provide isolation for thousands of years
- Bedded salt has high compressive strength and plasticity, allowing for gradual stress relief (fractures are essentially self healing)
- Salt resources are abundant, including large thick deposits with generally local fault zones
- Salt beds have been dated back over hundreds of millions of years, indicating dryness and long-term stability.

Reactivity of different geological materials with various hazardous waste types is important in case of container leakage. Certain geologic materials (e.g. limestone) are more reactive with wastes of low pH. As salt formations are highly soluble in water, waste containing water would increase the reaction. Crystalline rocks are incompatible with wastes of extremely high or low pH. In general, as wastes are to be drummed, waste characteristics that are important relate more directly to mine safety.

Many of these geological siting criteria can be determined from borehole exploration, electromagnetic/seismic/gravity surveying and remote sensing. However, the areal extent and persistence of these geological characteristics cannot be fully understood until the actual mining operations take place. This is particularly evident in host rocks such as crystalline units.

Economic/Institutional

Economic and institutional issues include a waste management strategy and the proposed method of cost estimation (such as discount rates, external costs, etc.). In general, as mined space is likely to be expensive, storage/disposal may be limited to highly toxic wastes that are difficult to treat or neutralize. Large scale resource management decisions are involved as use of underground space for waste storage/disposal will preclude other uses.

Economic decision rules must be established as tradeoffs between capital expenditures (high for mines) and operational costs with other alternatives will be essential. Also, risk assessments will be required to trade off the degree of risk of environmental damage with costs of facility construction.

In the U.S., extensive risk assessment activities are underway in determining the most suitable means of radioactive waste disposal. Very little emphasis has been placed on risks of underground space for hazardous waste disposal. The hazardous waste management strategy in the U.S. is focused on land disposal with the realization that leakage may occur. Much of the regulatory program relates to monitoring and management of that leakage. Although more expensive initially, storage/disposal in a salt mine could be managed to achieve zero leakage on a long-term basis. Relative cost effectiveness of the techniques will depend on the selected risk assessment criteria and decision rules established by the regulatory authority.

Overview of Federal Regulations

The U.S. EPA has treated mine disposal of hazardous waste as a special dipsoal category under RCRA. In the past, there has been some controversy over the regulation of mine disposal as it could technically be considered an injection well under the Underground Injection Control Program. Mine storage and disposal is to be treated under RCRA, Part 264, Subpart X. In general, the regulation would allow storage in mined space if it can be demonstrated that no adverse environmental impacts would occur. The burden of proof would be on the owner/operator of the facility.

At the present time, the United States is considering a total ban of hazardous waste storage and disposal in underground mined space (salt domes, bedded salt, and crystalline rock) and natural caverns. The ban would apply to all mining types including abandoned mines, active, or newly mined areas. The position of the United States on development of mined space for hazardous waste storage is inconsistent, as the use of dedicated mined space for high-level radioactive waste application is under consideration by the U.S. DOE.

Regulation of all radioactive waste is handled by the Department of Energy and the Nuclear Regulatory Commission while non-nuclear hazardous waste is regulated by the EPA. Due to the relative lack of activity/proposals related to hazardous waste storage and disposal in underground mined space (mostly due to cost), little research and development work has been done and the issue has received little regulatory treatment. Land disposal is used at thousands of sites currently, while mine disposal is virtually undeveloped in the United States.

The ban, proposed in an amendment to RCRA (HR 2867), is currently under review and if passed would temporarily ban storage of all hazardous waste in underground mined spaces. Hazardous wastes containing liquids would be permanently banned, and solid hazardous waste would be banned pending results of an EPA study. The two-year study is to be initiated by EPA to determine the feasibility and environmental impact of underground storage of hazardous wastes. It is likely that an operator would have to develop an extensive justification of a mine site before storage would be permitted. The two cases in the U.S. (State of Minnesota and PPG Industries, Inc., in Ohio) where this concept was pursued received sufficient public opposition to defer or terminate the projects.

The basis for the proposed amendments is primarily political and is not based on extensive technical analysis by the Federal government. Over the next two years the EPA study will provide the technical inputs upon which individual permitting decisions will be based. In particular, the disposed of wastes in salt deposit and crystalline rock areas would appear to be important issues due to the emphasis placed on these areas in the radioacive waste disposal programs. As a result, it does not seem likely that specific storage/disposal projects in dedicated salt or crystalline rock areas will be banned at the Federal level in the long term. Also, underground storage of petroleum products, which is allowed in the U.S., could have similar adverse impacts on ground-water resources if leakage occurred. It is more likely that cost constraints and pressure from local interest groups will have an impact on feasibility than technical factors.

Injection Wells

The use of injection wells in the United States for the disposal of liquid wastes has become widespread in recent years as a result of the passage of stricter laws and the implementation of regulations regarding the disposal of waste by the more traditional means. A practice that formerly was considered to be risky (in terms of the chances for success) and comparatively expensive, has become an accepted means of waste disposal not only because it has become economically attractive, but also because of a growing body of operational experience demonstrating that properly designed and constructed injection wells work effectively.

Recognizing the growth in the use of injection wells for a variety of purposes and the potential threat to potable ground-water resources, the U. S. Congress included provisions in the Safe Drinking Water Act of 1974 for controlling their use. Subsequently, the U. S. Environmental Protection Agency developed and implemented the federal version of UIC (Underground Injection Control) regulations. A number of states have their own UIC regulations, which must be at least as stringent as the federal ones. For those states which have not accepted primacy for controlling injection well practices, the federal government (U.S. Environmental Protection Agency) funds and administers the program.

As a result of improving technology and experience, the practice of injection well disposal is more widely understood and accepted. Nevertheless, there is still considerable ignorance on the part of both regulators and the public in general, and even on the part of users. This serves as a deterrent to the use of a viable disposal technology (in areas where suitable geologic conditions exist) and creates obstacles and delays to the implementation of plans and construction of facilities.

This report section presents an overview of injection well practices, with emphasis on the lower Paleozoic sedimentary rocks in the states of New York, Pennsylvania, Ohio, Michigan, and Illinois because of the similarities in the geologic characteristics of these zones with those considered in Ontario (Gartner Lee Associates, 1982) as having the potential as repositories for injected liquid waste. Additionally, matters dealing with the "public relations" and regulatory aspects of injections well disposal and the technical details of well design and construction are discussed.

Information used in preparing this section was obtained by telephone conferences with representatives of the various state regulatory agencies, by reviewing published and unpublished reports in Geraghty & Miller's files, and from Geraghty & Miller's experience in the design, construction, and permitting of injection wells.

Potential Injection Zone

A previous investigation (Gartner Lee Associates, 1982) identified a Cambrian sandstone overlying the Pre-Cambrian basement complex in the Southwestern Ontario Basin as a potential disposal horizon. This unit is present in the subsurface in a broad area paralleling the northern shore of Lake Erie and the southern shore of Lake Ontario in Canada and extending into New York State (Gartner Lee, 1982, Figure 11). Its thickness ranges from a feather edge on the north, inland of the lake, to its maximum on shore thickness of about 60 to 76 meters to the south. The unit also is present along the U.S.-Canadian border between Windsor and Sarnia, Ontario, where it is thickest in the general vicinity of Windsor (Gartner Lee Associates, 1982) along the eastern margin of the Michigan basin.

An equivalent formation in the United States in the Mount Simon Sandstone of Cambrian age in the states of Illinois, Indiana, Ohio, and

Michigan. Disposal wells tapping the Mount Simon have been drilled in each of these states and are used to dispose of a variety of fluids including brine, pickling liquors, phenols, ammonia, and hydrochloric and sulfuric acids. The Theresa and Potsdam Formations in New York State are of equivalent age, with the latter unit offering the greatest promise for underground waste disposal.

The Mount Simon is a regionally-extensive sandstone underlying virtually all of Michigan, Ohio, Indiana, and Illinois. In Michigan, and perhaps most relevant to this project,it is characterized by subrounded to rounded quartz grains that are generally coarse with a range of from medium to coarse. Typically, it is well cemented with silica. Basal portions of the unit contain a greater abundance of feldspar grains; glauconite, anhydrite, and green shale are present in minor amounts; locally the sandstone is cemented with dolomite. The presence of carbonate cements tends to reduce porosity and permeability; porosity decreases where the sandstone grades laterally into carbonate facies.

Detailed information on the Mount Simon Sandstone is lacking; only a few of the many thousands of oil wells drilled in Michigan have penetrated the Mount Simon. Analysis of a core taken from a brine disposal well (Passero, 1981) in St. Clair County (north of Lake St. Clair and roughly west of Sarnia) revealed porosities ranging from 4 to 20 percent; average permeability of that core was found to be 3.1×10^{-5} cm/sec.

The well where this core was taken is located in southeastern Michigan (Section 39, Township 4N, Range 15E) in an area where the Mount Simon

Sandstone is less than 60 meters thick. Reportedly, this well accepted 7.6 million liters per month of brine at an injection pressure of 5,688 kilopascals.

The nature of the Mount Simon Sandstone is better known in Illinois. It is tapped for potable water supplies in the northern part of the state and is used for liquid waste disposal in the central portion where it contains brine. Typically, the Mount Simon is dominantly a fine- to coarse-grained sandstone with some beds of shale and siltstone. In those areas where it is deeply buried and a potential injection horizon, it is well cemented and quartzitic; it also is generally more than 300 meters thick.

Reasonably good data are available from a Mount Simon disposal well located near Hennepin, Illinois, in Putnam County (Section 3, Township 32N, Range 2W) owned by the Jones & Laughlin Steel Corporation. At that location, the Mount Simon is about 335 meters thick. Permeabilities, based on core data, ranged two orders of magnitude--from 4.8×10^{-6} to 4.8^{-4} cm/sec. Porosities of the cores ranged between 8 and 22 percent; the core data correlated very well with sonic and porosity logs, making it possible to describe the section quite accurately. The bulk of the formation has permeabilities ranging between .0001 and .00001 cm/sec; porosities were between 9 and 12 percent.

In Ohio and Indiana, the Mount Simon has similar characteristics to those in Michigan and Illinois, and is used for the disposal of a variety of waste. In western and central New York State, two geologic formations--the Theresa and Potsdam Formations, of Cambrian Age--are potential injection zones. The Potsdam, which is the equivalent of the Mount Simon, is primarily sandstone that can contain streaks of dolomite and shale. The Theresa overlies the Potsdam and contains sandstone, sandy dolomite, and dolomite.

Additional information on the nature of the Mount Simon Sandstone and its capability to accept waste is contained on Table 3, which lists a number of disposal wells using that horizon and, where available, data on the permeability and porosity of the reservoir, its thickness and depth of occurrence, injection rates and pressures, and volumes disposed.

Examination of Table 3 shows that porosities of the Mount Simon are about 10 to 12 percent, but that permeabilities can vary considerably. Additional information on these wells is contained in our files.

Of particular interest are the wells located in Butler and Allen Counties in Ohio (Wells 14, 15, 16, 18, and 20 on Table 3) and the Hooker Chemical Co. well (Well 1 on Table 3) in New York State. The Mount Simon at the locations in Ohio occurs at depths of 850 to 880 meters, is about 90 to 106 meters thick, and has porosities of 10 to 14 percent; its equivalent in New York is present at a depth of 862 meters, but is only 24 meters thick.

It is believed that the performance of these wells would be similar to what one might expect from a well tapping the Cambrian sandstone at a suitable location in Ontario. Examination of the data on Table 3 shows that injection pressures for Wells 16, 18, and 20 ranged from 3,744 to

Table 3. Selected Data on Disposal Wells Tapping the Mount Simon Sandstone or Its Equivalent.

Site/Company	County	Well No.	Depth (meters)	Interval (meters)	Thickness (meters)	Rate (liters per minute)	Pressure (kilo-pascals)	Porosity (percent)	Permea-bilities cm/sec x 10^{-6}	Waste
NEW YORK										
1. Hooker Chemical		Buffalo, N.Y.2	934	863 - 887	24	545	10,342	--	--	30% HCl
2. Bethlehem Steel		Buffalo, N.Y.3	1,314	1,158 - 1,319	161	95	6,205	--	--	Pickle liquor
INDIANA										
3. FMC Corp.	Vermillion		1,880	1,603 - 1,877	274	189	6,895	6	5.8- 7.7	Brine-200,000
4. Bethlehem Steel	Porter	S28 T37N R6W	1,299	773 - 1,299	526	473	4,827	9	--	Brine, H_2SO_4
5. Bethlehem Steel	Porter	S30 T37N R6W	1,202	765- 1,202	437	473	4,827	10-20	19.8-97	NH_4, phenols, cyanide
6. Bethlehem Steel	Porter	S29 T37N R6W	1,311	771 - 1,303	532	121	103	10-20	19 -97	NH_4, phenols, cyanide
7. Midwest Steel	Porter	S25 T37N R6W	1,313	658 - 1,298	640	1,041	0-207	18	38 -48	HCl
8. Indiana General	Porter	S16 T35N R5W	1,386	858 - 1,389	531	--	345	--	--	NH_4Cl
ILLINOIS										
9. U.S. Steel	Lake	S29 T37N R8W	1,311	738 - 1,302	564	795	1,379	14.3	412	Pickle liquor
10. Inland Steel	Lake	S14 T37N R9W	1,325	719 - 1,323	604	208	0-1,586	12	305	Pickle liquor
MICHIGAN										
11. Chemtron	Ottawa	S30 T5N R14W	1,801	--		132	1,551-1,724	--	--	H_2SO_4, HCl, NH_4
12. Chemtron	Ottawa	S30 T5N R14W	1,797	1,404 - 1,797	393	132	1,551-1,724	--	--	Pickle liquor

Table 3. (Continued)

Site/Company	County	Well No.	Depth (meters)	Interval (meters)	Thickness (meters)	Rate (liters per minute)	Pressure (kilo-pascals)	Porosity (percent)	Permea-bilities cm/sec x 10^{-6}	Waste
OHIO										
13. Empire Reeves Steel	Richland	Section 16, Madison Twp.	1,543	1,518 - 1,543	25	57	2,069	10	8.7	38 million liters disposed
14. Armco Steel	Butler	Section 8, Lemon Twp.	1,005	900 - 986	86	337	2,965	10	241	92.7 million liters disposed
15. Armco Steel	Butler	Section 8, Lemon Twp.	1,001	896 - 985	89	254	552	10	241	129 million liters disposed
16. Vistron	Allen	Section 2, Shawnee Twp.	955	847 - 955	108	458	5,392	14	--	1,177 million liters
17. U.S.S. Chemical	Scioto	Green Twp.	1,712	1,681 - 1,696	15	216	9,653	12	26	500 million liters
18. Vistron	Allen	Section 11, Shawnee Twp.	967	853 - 958	105	757	4,978	14	--	1,173 million liters
19. Callio Chemicals	Lake	Perry Twp.	1,851	1,807 - 1,847	40	--	--	--	--	--
20. Vistron	Allen	Section 2, Shawnee Twp.	965	847 - 955	108	723	3,744	14	--	68 million liters

5,392 kilopascals: accompanying injection rates ranged from 458 to 757 liters per minute. The Armco wells (Wells 14 and 15) operate at lower rates (254 and 337 liters per minute) and lower injection pressures--552 and 2,965 kilopascals (the latter figure appears high and may be the result of plugging). Of particular importance is the fact that two of the Vistron wells (Wells 16 and 18) each handled in excess of 1,135 million liters of waste consisting of waste with a total dissolved solids content of 39,000 mg/L (milligrams per liter) composed of ammonia, sulfate, cyanide, aldehydes, organic acids and nitriles. The total quantity disposed at the facility using these three wells was 2,419 million liters (through 1974). As of this date, two of the wells have been operating successfully for 14 years and a total volume of 9.8 billion liters has been injected. Currently, these wells are handling a combined total of 1,363 liters per minute at a pressure of 5,516 kilopascals (permitted pressure is 5,792 kilopascals). The wells have not experienced any significant problems; no workovers have been required. Thus, in spite of the comparatively low porosities (10 to 14 percent) and a thickness of 91 meters to 107 meters, the reservoir has accepted and stored this quantity of liquid waste, and is capable of handling even more.

Disposal in the Cambrian Sandstone

In Ontario--Basic Research

Available records show that the Mount Simon Sandstone and its equivalents, the Theresa and Potsdam Formations, are widely used for disposal via injection wells in Ohio, Indiana, Illinois, and New York. In spite of the fact that porosities and permeabilities are comparatively low, these formations have been used successfully and will continue to be in the future. Judging from material contained in the literature and data describing the Mount Simon in the states--particularly in Michigan--and descriptions contained in the Gartner Lee Associates report, it appears that the "Cambrian" sandstones throughout the entire area have similar properties; it is reasonable to assume that a properly designed and constructed injection well at a favorable location in Ontario would serve as an effective means of waste disposal. However, a number of precautions would have to be observed in order to construct a long-lasting, efficient facility.

The nature of the Cambrian sandstone, regulatory requirements (and attitudes), and probable public concern and opposition dictate the need for a thoroughly planned well design and program of investigation. Procedures used to develop the design involve detailed geologic research, based on available data, to develop a system description. Aside from regional geologic data, sources such as oil and gas well records (wildcat, producing, and abandoned) in government agency files and, wherever possible, in private files should be searched to obtain geophysical logs, core data, plugging and abandonment records, and drilling and drill-stem test reports.

The purpose of the research is to make a preliminary determination about the nature of the potential injection zone (its top, thickness, porosity, permeability, and the quality of the formation fluid), identify potential confining beds, and locate the base of potable water. In addition, information on drilling problems (caving zones, low or high pressures, lost circulation etc.) will be developed. Concurrently, work should be done to estimate the chemical nature and quantity of the waste to be injected. Knowledge of the geologic system will enable the designing of a well affording the greatest degree of environmental protection.

The well probably will be constructed with three strings of casing. These are (1) a short conductor casing to provide protection from washout and rig collapse during drilling, (2) a surface casing set to a point below the base of potable water, and (3) a long string or injection casing set through the confining sequence to a point just above the top of the potential injection zone. The diameters of the casings will be dictated by the diameter of the injection tubing and couplings which, in turn, will be dictated by the rate at which the waste is to be injected. Generally, a 3 meters per second limiting velocity can be used for determining tubing diameter.

Well Design and Construction--Project Planning

Injection Zone

Any potential disposal horizon in the Cambrian Sandstone can be assumed to possess a low porosity and permeability. The most efficient completion should penetrate and be open to the entire thickness of the disposal formation. Judging from the various well records examined and descriptions of the formation, it appears to be sufficiently consolidated to permit an open-hole completion. Some older injection wells are completed in basically the same way as an oil well. The reservoir (in this case, an injection zone) is cased off and cemented; communication with the reservoir is achieved by perforating the casing and cement. This results in an extremely inefficient installation because of the small open area through which injected fluid can move. As a consequence, friction losses and injection pressures (and pumping costs) will be higher than they should be and there will be an incresed tendency for plugging, which would require shutdown and rehabilitation. A perforated casing completion should not be considered. If the hole will not stand open, an underreamed hole with a screen and gravel pack (well rounded, graded silica) should be used.

To minimize formation damage during drilling and completion, the fluid used for these operations should be no denser than that needed to control formation pressure. Solids content should be kept to an absolute minimum to prevent plugging and formation damage. Solids removal and filtration to remove particle sizes of two microns or larger is recommended for the sanding/desilting system used during drilling operations. Additionally, any fluid and filtrate should be custom-made to minimize damage by swelling or dispersion of clays. (Evaluation of any currently available cores to determine clay content and composition would be useful in formulating the proper drilling fluid program.)

One way of drilling the well would be to drill hole to the top of the potential injection zone, install the long casing string, cement it in place, change the drilling fluid to one suited for drilling the injection zone, and complete the well. As an alternate, a foam drilling fluid system or air could be considered. It also would be useful to plan on underreaming the open pilot hole after logging using a "designed" fluid system to provide a greater open area and remove any damaged formation. In no case should a "conventional" drilling mud be used as it will result in formation damage that cannot be completely repaired.

The literature indicates that the various Cambrian sandstones can contain carbonate cement. Its occurrence and distribution is unknown. To aid in completing an efficient well, acidizing should be considered to improve permeability in the near vicinity of the borehole. A service company experienced in this technique (in this area) should be consulted when planning the program.

Additionally, hydraulic fracturing (fracing) could be considered. However, use of this technique probably would be viewed with some scepticism, or even prohibited, by the regulators because of their concern over the potential for fracturing/rupturing of the confining sequence. The current state of the art in fracing is fairly advanced and there are methods for predicting fracture height and of designing a fracture program suited to the environment at the site. Again, a service company such as Halliburton Services, should be consulted.

The drilling program for the injection well should be designed to extract the maximum amount of subsurface information on the properties of the confining bed and the injection zone to enable the well to be completed as the injection well. This can be accomplished by drilling a pilot hole to the anticipated total depth in pre-Cambrian basement rock and collecting the various data as the drilling progresses. As an alternative, the pilot hole could be drilled to the anticipated top of the injection zone while collecting the subsurface data, the various casing strings set and cemented and the hole completed after changing the drilling fluid system. This method entails financial risk as it requires virtually all of the well to be constructed before knowing wheter or not the well will function. Consequently, the former method is preferred as long as the proper type of drilling fluid is used to minimize formation damage.

Sampling, Coring, Testing

During pilot hole drilling, formation samples are collected by a trained geologist, drilling time and weight-on-bit records and graphs are prepared, and four-inch-diameter cores are collected from selected points in the confining bed and injection zone. Information gained from the geologic research is used to determine the intervals to be cored (provision is included in the specificatoins for taking additional cores if conditions warrant).

Confining bed cores are analyzed for vertical permeability, porosity, density, and mechanical properties (strength, modulus of elasticity). Injection zone cores are analyzed for the same properties with the addition of horizontal permeability and mineral composition, with particular emphasis on clay composition and content.

Geophysical logs made in the pilot hole (its diameter should be sufficient to compensate for above-hole effects on the logs) should include natural gamma ray, dual-induction logs (LL8 or SFL), self potential, temperature, caliper, and fracture finder. Porosity logs should include compensated neutron, density, and borehole compensated sonic. Caliper logs should be run in any holes that are reamed in order to permit acccurate calculation of cement volumes.

Borehole testing after pilot hole completion and geophysical logging should include the use of a repeat formation tester (RFT) to collect formation fluid samples from selected intervals in the injection zone and from zones above the confining bed sequence. The pilot-hole diameter should be limited to a size capable of allowing the RFT to be set and seal the point to be sampled. Fluid samples, particularly from the injection zone, should be reserved for analysis to aid in compatibility determinations with the waste fluid. The RFT can be used to perform "drill-stem" testing. This can be done to collect preliminary data, but a standard drill-stem test(s) (DST) should be performed to collect precise data on injection zone permeability and evaluate formation damage.

An injection test using the proper type of fluid (custom-made brine to prevent formation damage) could be performed by packing off the injection zone and injecting the fluid while measuring the bottom-hole pressure. This will afford the most definitive means of evaluating reservoir performance.

Completion

The well would be completed by reaming the pilot hole to the appropriate diameter to accommodate casing and cement following the emplacement of a drillable bridge plug just above the top of the injection zone. The reaming must be done with the proper type of bit assembly to eliminate the potential for deviation between the reamed hole and the track of the pilot hole. Deviation surveys would be taken in both pilot and reamed holes and the data compared as the reaming progresses to insure that the holes are tracking each other.

The casings would be standard threaded and coupled API-grade and weight pipe set and centralized within the boreholes. The bottom 60 to 100 feet or so of the injection casing should be made from metal that will not corrode in the presence of waste. The annulus cement would be emplaced by the Halliburton method using a guide shoe and, if desired, a float collar. The cement blends used should be compatible with the formation fluids to minimize deterioration. Lost circulation materials such as gilsonite and flocele (cellophane) could be used as dictated by field conditions. The cement to be placed around the base of the injection casing (tail-in cement) must be compatible with the waste. If necessary, epoxy "cement" such as Epseal (a Halliburton trade name) should be used.

Integrity of the injection casing would be checked using a pressure test. A pressure equal to about 1.25 times the anticipated injection pressure should be used. This would be performed prior to the drilling of the cement in the bottom of the casing. Additionally, a cement-bond log would be made of the injection casing as well as VDL (Schlumberger trade name) or some other form of log providing a continuous film recording of the wave-train display.

Sound design practice dictates the use of a tubing and packer to convey the waste and isolate it from the injection casing. The tubing must be fabricated from a waste-compatible metal. Consideration should be given in the tubing design for temperature changes in the waste to prevent excessive stress due to contraction and expansion and the resultant failure.

The packer material and elements must be of metals and compounds that are waste compatible. A retrievable unit should be used, preferably a tension set type because the upward force created by the injection pressure will tend to hold it in place. Consideration must be given in the design to any tension reduction arising from tubing expansion.

The annulus between the tubing and injection casing should be filled with a clean water (brine) with corrosion inhibitors added. This will add to the life of the well and facilitate packer removal if it is needed at some time in the future. Any portion of the well-head assembly (casing head, tubing hangar, valves, etc.) that will come in contact with the waste should be fabricated from material that will resist corrosion from the waste.

Monitoring

Aside from the technical matters dealing with the well's design and details of the program of subsurface data collection and testing, the permitting agency will require the collection and periodic submission of data on injection rates and pressures and cumulative volume of wastes disposed, as well as its composition. Sound well management dictates the need for these data to be collected. Continuous records of injection pressure and rate should be made, as well as cumulative volumes disposed (per day or per week). Annulus pressure should be monitored on the same basis. All of this information should be kept on file permanently at the facility as well and submitted in accordance with permit requirements. As added protection, the system should be equipped with high and low pressure alarms in the pipeline between the injection pumps and the well head.

According to the Ontario regulations, the Minister may at his discretion require the drilling and monitoring of one or more observation wells into the receiving formation and/or the deepest overlying fresh-water horizon. Should both zones have to be monitored, a dual-zone completion in a single well should be considered. If only the deepest fresh-water-bearing formation is required to be monitored, it can be accomplished in the annulus outside of the surface casing.

In this case, the reamed hole in which the surface casing will be set is drilled to a size approximately 200 millimeters greater than the diameter of the surface casing to permit the installation of a 60 millimeter diameter tubing with turned down couplings and a temporary tremie pipe for cementing. The monitor tube is set to the desired depth and communication with the "monitor" zone is achieved either by gravel packing the zone (in this case, a screen is used) or by completely cementing the pipe in place and directionally perforating it. The monitor zone can be picked from the logs and the quality data from the RFT samples. Development of the zone can be accomplished using acid treatment.

Drilling Contract

The drilling and construction of an injection well represents a considerable investment on the part of the owner. Usually, it is done by contractors whose principal business is oil well drilling. While there are many similarities between the two, there are significant differences that require a greater degree of control than is ordinarily given to the drilling of an oil well. Successful completion requires the services of a contractor experienced in injection wells because of the care that must be taken in avoiding formation damage (particularly in a reservoir with low porosity and permeability) and in collecting the information necessary to complete the well properly and demonstrate to the satisfaction of the regulator that suitable conditions for injection exist. Typically, an oil well drilling contractor is interested primarily in "making hole". This experience will influence his behavior when he is working under the more rigidly controlled conditions used in the drilling of an injection well and can lead to problems in construction and efficient completion. As a consequence, it is wise to select a qualified contractor with experience in injection wells.

Based on Geraghty & Miller's experience, the wisest approach is for the OWMC to enter into a turnkey contract with a qualified firm to drill and construct the injection well. Typically, an owner will contract to have the well drilled, but it is his responsibility to purchase all materials and services and coordinate deliveries, etc., with the activities of the drilling contractor. The turnkey contract using a strict set of specifications is preferred because it places all responsibility directly on the drilling contractor. The specifications generally call for a lump sum base price bid with unit adjustments for quantities of materials used (casing, cement, etc.), footages drilled, and services performed (logging, coring, RFT and drill-stem testing, etc.). Provisions also are included for standby time, but only as approved by the owner or his representative. If desired, provisions can be included in the specifications for bonding in the event the well has to be abandoned because of contractor performance. The contract for the injection well should be separate from the contract(s) for site work and surface facilities. This will give the OWMC more control over the selection of the drilling contractor and his performance.

Waste Stream

During the initial project planning, attention must be given to determining (if only estimating) the quantity and quality of the waste water. Quantity (rate) will dictate the size of the well; quality, the nature of the material used in its construction. Attention must be paid to the probable composition of the waste to permit estimates of formation and formation fluid compatibility to be made. Because of the low porosity of the reservoir, it is recommended that some form of filtration be required to minimize the potential for plugging; filtration down to a two-micron size should be considered. Additionally, an estimate of the temperature variations of the waste stream should be made for use in designing the tubing string.

Public Relations

The use of an injection well for waste disposal is a controversial topic; for that matter, so is the operation of a hazardous waste treatment and storage facility. It is quite likely that the OWMC will be faced with organized opposition either to the use of an injection well or to the entire facility. In both cases, the opposition will be strong, vocal, and possibly well organized. Objections to the use of an injection well will be based on a combination of ignorance and fact and the OWMC should be well prepared to deal with the situation.

Primary concerns will focus on questions dealing with the treated waste's ultimate fate in the reservoir--how a reservoir that is saturated with fluid can store and accept even more fluid; the effect that injection will have on earthquake activity; and the upward migration of the injected fluid into fresh-water aquifers either through the confining bed or via abandoned and improperly plugged boreholes. With regard to the latter, experience at Sarnia will be cited.

The OWMC should be prepared to deal with the public and these questions. An information program should be set up. Public participation should be encouraged well in advance of the drilling. It is suggested that a "Panel of Injection Well Experts" should be formed to assist in dealing with the public at regularly scheduled meetings where presentations on injection wells in general and specific details of the program are given. Local government leaders should be encouraged to participate in the information program.

Overview of Regulations

The permitting agency will be concerned with basically the same topics as the public and, of course, the technical details of the well design and the program. State regulatory agencies and the U. S. Environmental Protection Agency (EPA) have basically the same concerns and requirements as the Petroleum Resources Section of the Ministry of Natural Resources. Copies of the regulations for the state of Florida are contained in Attachment B. This state's regulations have been included as they are quite comprehensive, based on the five-fold injection well classification devised by the EPA, and were formulated by the Florida Department of Environmental Regulation with advice from a group of outside technical experts. An injection well at the OWMC facility would be designated as a Class I well. Examination of the Florida regulations shows that they are quite flexible and are based primarily on performance with a few exceptions. Because most of Florida's disposal wells are constructed in carbonate rock sequences, most of which have been affected by dolomitization and solution, a unique environment exists. Lost circulation and cementing problems are common. As a consequence, extra large annuli are required by the regulations to permit the emplacement of cement. Such would not be the case in Ontario.

As indicated in the previous section on Monitoring, the permitting agency will require the collection and submission of data on injection rates and pressures and volumes handled as well as the composition of the waste, and observation wells may be required.

The granting of the permit could be facilitated by forming a Technical Advisory Committee to assist in reviewing the program and advising the Petroleum Resources Section. The members of the committee would be experienced technical personnel (geologists, chemists, engineers) drawn from local and provincial agencies who normally cooperate or work with the Petroleum Resources Section. This group, which would be purely technical in nature would serve as an advisor to the Section and would meet with the OWMC and its consultants prior to and during the course of the drilling and testing program. In this way, the lines of communication between regulator and applicant are kept open and the program can be completed with a minimum of difficulty, aside from drilling problems.

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ATTACHMENT A

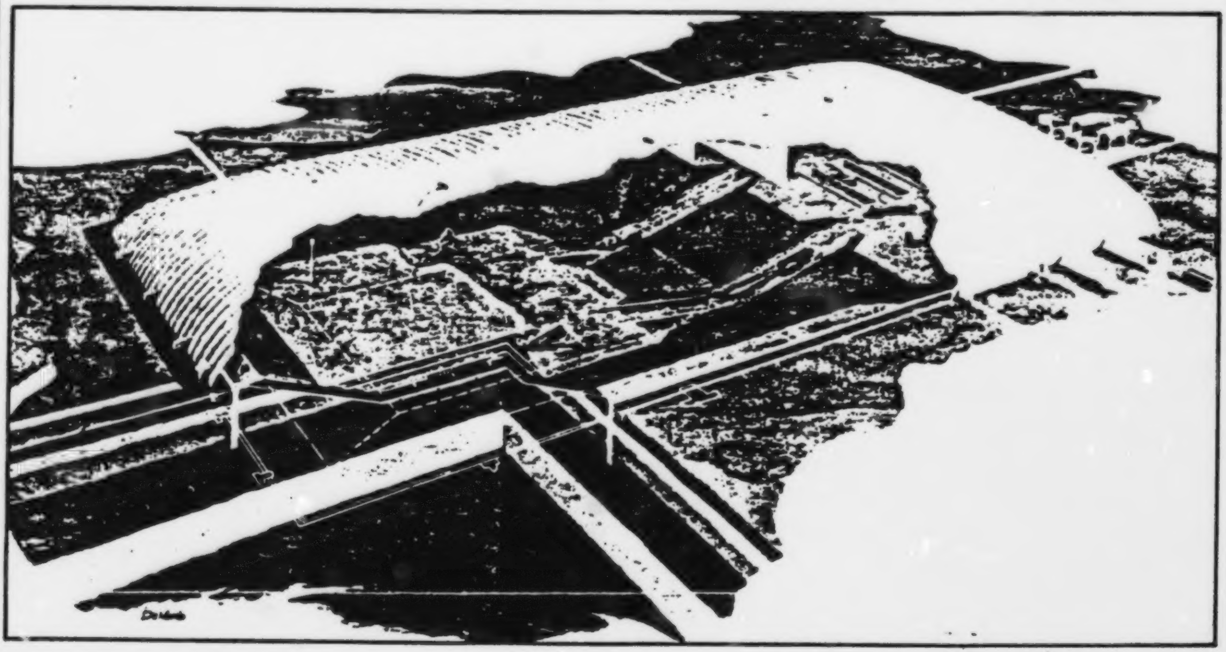
CECODOME

INDUSTRY EXCLUSIVE

FACT SHEET

environmental questions from CECOS International Number 8

CECOS Introduces The CECODOME™



Cutaway view of the CECODOME™ shows operations of the Livingston Secure Chemical Management Facility under the polyester-based canopy.

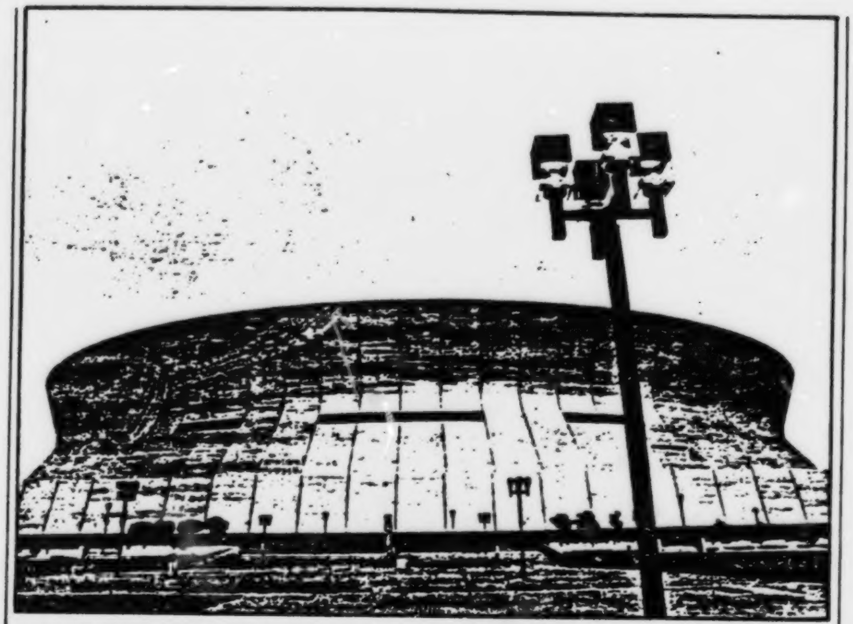
Maintaining its commitment to exceptional environmental standards, CECOS International, technological leader of the chemical waste services industry, introduces an industrial innovation: CECODOME™, the largest free standing, ground mounted air structure in the world to be installed early in 1984 over the company's Secure Chemical Management Facility in Livingston, Louisiana.

Coupled with CECOS' triple liner protection system in Livingston's existing land management facility, the CECODOME™ will offer environmental protection as never before. For the first time in the chemical waste services field, the possibility of precipitation generated leachate will be eliminated as the CECODOME™ protects the operating facility from infiltration of rainwater.

Annually, Livingston has an average 60" of rainfall and CECODOME's™ tough, polyester-based canopy with PVC (polyvinyl chloride) coating will repel the precipitation and prevent liquid contact with the facility's solid chemical materials. The leachate previously created by the rainfall required collection, treatment and ultimate disposal in CECOS' wastewater disposal facilities.

CECODOME™ will measure a giant 350' x 650' with 2,000 linear feet at its perimeter. It will cover 227,500 square feet of ground. Construction will consist of nearly 300,000 square feet of fabric, thousands of feet of steel cables — ⅞" thick, hundreds of steel anchors and ten miles of seaming. The highest point of CECODOME™ from the ground level will be 63 feet or nearly seven stories.

By comparison, the Louisiana Superdome has a diameter of 680', but its materials are concrete and steel. The next largest similar structure to CECODOME™ is believed to be a 400' x 400' facility erected during the construction of a Canadian refinery.



The CECODOME™ is so large that only one of the air structures would fit inside the Louisiana Superdome.

Self-supporting air structures have been built over stadiums, civic centers, shopping centers and in the industrial area, but CECODOME™ will mark the first time the venture has been made in the chemical waste services field.

It will take four to five months to produce the fabric and ship materials for the CECODOME™, and several weeks of preparation for inflation of the structure over the Livingston disposal facility. Actual inflation of the CECODOME™ will be complete in less than one hour.

Specialized blowers with propellers similar to those used in airplanes will continually push air into the structure, changing the air 2½ times or over 22-25 million cubic feet per hour. Nearly nine million cubic feet of air will be made per change.

There will be two sets of electrical blowers: six inflation blowers and six ventilation blowers. The six inflation blowers have a capacity of 78,000 cubic feet per minute and the ventilation blowers each have a capacity of 60,000 cubic feet per minute, for a composite air displacement capability of 360,000 cubic feet per minute for the ventilation blowers. Should all blowers be in operation at once, the volume of air change would be 438,000 cubic feet per minute.

The facility will provide three auxiliary gasoline driven blowers to maintain inflation of the CECODOME™ in case of a power outage.

CECODOME™ will be constructed sequentially in 12 sections of fabric which will then be joined together on site.

To erect the CECODOME™, blower equipment is spotted at the facility to match the openings of the CECODOME™. Then the equipment is connected and tested. Each of the sections, weighing more than two tons, is joined together mechanically through a special seaming process. The fabric's cable harness is tied down every eight feet by a series of augers installed in the ground. The only conventional structural components of the CECODOME™ are the frames for the airlocks to allow vehicle entry and exit.

The CECODOME™ is anchored to the ground by reusable augers making the structure portable. To move the DOME, the structure is deflated, partially disassembled and moved.

Air inside the CECODOME™ will be controlled with a number of gravity dampers. Air quality specifications will be in compliance with OSHA regulations. The CECODOME™ will allow for better air monitoring, and dust control will be supplied by watering trucks as in the traditional chemical waste facility. All personnel will be equipped with proper respirators, eye goggles and hard hats as in outdoor operations.

Fire extinguishers will be made available inside the facility in accordance with government standards. No volatile materials will be placed in the Secure Chemical Management Facility, however, CECODOME's™ fabric is self-extinguishing for protection.

During a hurricane, (defined as winds beyond 74 miles per hour) the harness structure will be adjusted to withstand the increased velosity. For winds in excess of 80 to 90 MPH, the structure will be deflated and tied down.

The structure will provide seven personnel doors including six emergency exits. Two airlocks will provide vehicle access; all doors will be made of aluminum.

The CECODOME™ offers many advantages in the industrial waste management area. It will:

1. Eliminate contaminated water (leachate) in the facility as a result of rainfall, and the possibility of the liquid's migration into the environment.
2. Provide all weather operations in a comfortable greenhouse-type setting. Generators need not store waste materials on their site due to inclement weather. Storage provisions previously added considerably to disposal problems at the generator's site.
3. Provide the opportunity to better monitor air quality of the facility.
4. Provide resistance to the sun through the fabric's coating that protects it against ultra-violet light, and create natural lighting through its 20% translucency.
5. Supply an industrial blower system that will keep fresh air flowing throughout the facility at all times.

All of these advantages are continuing evidence of CECOS' total commitment to quality and service to industry, and dedication to providing maximum protection to our environment.

Aerial view of the CECODOME™ shows the massive area the air structure will occupy in Livingston.

Quick Facts About CECODOME™

MATERIALS:	Canopy of polyester-based polyvinyl chloride (PVC) coating Aluminum airlocks Several hundred reusable steel anchors Thousands of feet of steel cable, ⅞" thick 10 miles of seams
TOTAL SIZE:	350' x 650' covering 227,500 square feet of ground
HEIGHT:	63' or 7 stories
BLOWERS:	Six ventilation, 60,000 cubic feet per minute capacity (electrical) Six inflation, 78,000 cubic feet per minute capacity (electrical) Three auxiliary gasoline driven blowers
OPENINGS:	Two vehicle airlocks; automatic vents Seven Personnel doors including six emergency exits
APPROXIMATE COMPLETION DATE AND LOCATION:	Early 1984; CECOS International's Secure Chemical Management Facility in Livingston, Louisiana.

CECOS
INTERNATIONAL
2321 Kenmore Avenue
Buffalo, New York 14207
(716) 873-4200

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ATTACHMENT B

Underground Injection Control Regulations for Florida

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17-28.11 Introduction.

(1) Purpose.

(a) The purpose of Chapter 17-28, FAC, Underground Injection Control, is to protect the quality of the State's underground sources of drinking water and to prevent degradation of the quality of other aquifers adjacent to the injection zone that may be used for other purposes. This purpose may be achieved through regulations that govern the construction and operation of injection wells in such a way that the injected fluid remains in the injection zone, and that unapproved interchange of water between aquifers is prohibited.

(b) The permitting concept of a Technical Advisory Committee (TAC), which has been successfully used in the last four years, is formally described in this rule. The Technical Advisory Committee evolved from a need for interagency coordination to facilitate the permitting process, and to provide the permitting authorities the advice from the several disciplines necessary to adequately evaluate complex deep injection well system permit applications. A Technical Advisory Committee will be established in each Department District to assist and provide advice to the permitting authority on the technical aspects of underground injection for subsurface disposal. The Technical Advisory Committee is normally composed of representatives from the Department's District and Tallahassee offices, the appropriate water management district, United States Geological Survey, and the United States Environmental Protection Agency. The Technical Advisory Committee is to be chaired by a representative of the Department permitting authority, who is to be responsible for forwarding the Technical Advisory Committee recommendations to the permitting authority. In the event a water management district also issues a permit, the water management district representative on the Technical Advisory Committee will be responsible for forwarding the Technical Advisory Committee recommendations to the water management district permitting authority. A permitting authority is not bound by a Technical Advisory Committee recommendation and may reject, modify, or amend the recommendation provided its actions are consistent with the provisions of this rule.

(2) Declaration and Intent.

(a) This rule establishes a State Underground Injection Control Program that is appropriate to the hydrogeology of Florida and is con-

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sistent with the requirements of the federal Underground Injection Control Program.

(b) It is the intent of this rule that the injection of wastes underground shall not interfere with any designated use of ground water as specified in Rule 17-3.403, FAC, or cause violations of water quality standards for underground sources of drinking water.

(3) Scope.

(a) Chapter 17-28, FAC, covers all injection wells defined in Rule 17-28.13(1), FAC, as Class I, III, IV or V wells. Regulations in Chapter 17-21, FAC, no longer apply to injection wells.

(b) Injection wells defined as Class II wells in Rule 17-28.13(1), FAC, are not included in this rule. Class II wells are regulated by the Florida Department of Natural Resources, Bureau of Geology, under Chapter 377, F.S., and Rules 16C-2, and 16C-26 through 16C-30, FAC.

(c) Specific inclusions. The following wells are included among those types of injection activities which are covered by this chapter. [This list is not intended to be exclusive but is for clarification only.]

1. Any injection well other than a Class II well located on a drilling platform inside Florida's territorial waters.

2. Any dug hole or well that is deeper than its largest surface dimension, where the principal function of the hole is emplacement of fluids.

3. Any septic tank or cesspool used by generators of hazardous waste, or by owners or operators of hazardous waste management facilities, to dispose of fluids containing hazardous waste.

(d) Specific exclusions. The following are not covered by these regulations:

1. Injection wells located on a drilling platform or other site that is beyond Florida's territorial waters.

2. Any septic tank systems subject to Chapter 10D-6, FAC, and any individual or single family residential waste disposal systems.

3. Any dug hole which is not used for emplacement of fluids underground.

4. Any well utilized in conjunction with the operation of an earth-coupled heat pump system as defined in Rule 17-28.12(20),

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FAC.

(4) The effective date of Chapter 17-28, FAC, shall be April 1, 1982.

Specific Authority: 373.309, 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

17-28.12 Definitions. When used in this Chapter, the following words shall have the indicated meanings unless the context clearly indicates otherwise:

(1) "Abandoned well" means a well the use of which has been permanently discontinued or which is in a state of disrepair such that it cannot be used for its intended purpose or for observation purposes.

(2) "Acidizing" means the injection of acid through the borehole or "well" into a "formation" to increase permeability and porosity.

(3) "Allowable stress" means the allowable stress for a material is the maximum stress that may be safely applied, which equals the yield-point stress divided by an appropriate factor of safety.

(4) "Annular monitor well" means any pipe or tubing which is permanently placed in the annulus of an injection well to monitor a discrete zone.

(5) "Annulus" or "Annular Space" means any artificially created void existing between a well casing or liner pipe and a borehole wall or between two casings or between tubing and casing or liner pipe.

(6) "Aquifer" means a geological formation, group of formations or part of a formation that is capable of yielding a significant amount of water to a well or spring.

(7) "Area of review" means the area surrounding an "injection well" described according to the criteria set forth in Rule 17-28.13(4), FAC, or in the case of a well field permit, the project area plus a circumscribing area with a fixed width of not less than one mile.

(8) "Casing" means a pipe or tubing of appropriate material, of varying diameter and weight, lowered into a borehole during or after drilling in order to support the sides of the hole and thus prevent the walls from caving, to prevent loss of drilling mud into porous ground, or to prevent water, gas, or other fluid from entering or leaving the hole.

(9) "Catastrophic collapse" means the sudden and utter failure of adjacent or overlying strata which has been caused by removal of underlying

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materials.

(10) "Cementing" means the operation whereby a cement slurry is pumped into a drilled hole or forced behind the casing.

(11) "Centralizer" means a casing accessory used to properly align a casing within the open hole, or to properly align one casing within another casing, or to properly align a tubing within a casing.

(12) "Cluster Well" means a well where two or more monitor tubes of different lengths are emplaced within a single borehole to monitor two or more discrete zones.

(13) "Confining bed" means a layer of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

(14) "Confining zone" means a geological formation, group of formations, or part of a formation that is capable of limiting fluid movement from an injection zone.

(15) "Contaminant" means any substance which is harmful to plant, animal or human life.

(16) "Conventional mine" means an open pit or underground excavation for the production of minerals.

(17) "Department" means the Department of Environmental Regulation or its successor agency or agencies.

(18) "Disposal Well" means a well used for the disposal of waste into a subsurface stratum.

(19) "Dry well" means a well usually lined or filled with rocks that holds drainage water until it percolates into the ground.

(20) "Earth-coupled heat pump system" means any space heating/cooling system in which water containing no additives is circulated through a continuous section of buried pipe such that the earth is utilized as a thermal exchange medium, but no fluid is either extracted from or injected into any underground formation.

(21) "Emergency disposal method" is an effluent disposal method that, after prior Department approval, is only available for short term discharge under emergency conditions when the primary disposal method is inoperable.

(22) "Exempted aquifer" means an aquifer or its portion that meets the criteria in the definition of "underground source of drinking water" but which has been exempted according to the procedures of Rule 17-28.13(3)(a), FAC.

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(23) "Experimental technology" means a technology which has not been proven feasible under the conditions in which it is being tested.

(24) "Exploratory pilot hole" means a hole drilled for the purpose of obtaining subsurface information or as a guide for the drill bit to follow when drilling the final hole.

(25) "Exploratory well" means a cased well drilled in an area in which there is limited hydrologic and geologic data, to obtain sufficient data to determine the feasibility of injection. With prior Department approval, an exploratory well may be plugged and abandoned, converted to a monitor well, or used as an injection well if it meets all applicable standards for a Class I well.

(26) "Facility or activity" means any installation as defined by Section 403.031(8), F.S., that is subject to regulation under the Underground Injection Control Program. These terms shall be deemed to include federal facilities and activities.

(27) "Factor of safety" means the ultimate load divided by the safe load, or the ultimate strength divided by the allowable stress.

(28) "Fault" means a surface or zone of rock fracture along which there has been displacement.

(29) "Flow rate" means the volume per unit time of the flow of fluids which emerge from an orifice, pump, turbine or which pass along a conduit or channel.

(30) "Fluid" means material or substance which flows or moves, whether in a semisolid, liquid, sludge, gas, or any other form or state.

(31) "Formation" means a body of rock characterized by a degree of lithologic homogeneity or similarity which is prevailingly, but not necessarily, tabular and is mappable on the earth's surface or traceable in the subsurface.

(32) "Formation fluid" means fluid present in a formation under natural conditions as opposed to introduced fluids, such as drilling mud.

(33) "Ground water" means water below the land surface in a zone wherein all of the interstices are filled with water.

(34) "Hazardous waste" means a hazardous waste as defined in Rule 17-30.03(1), FAC.

(35) "Hydrogeology" means the branch of hydrology that deals with ground water, its occurrence and movements, its replenishment and depletion, the properties of rocks that control the ground water movement and storage, and the methods of investigation and use of ground water.

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(36) "Injection pressure" means the pressure required to inject fluid, as measured at the wellhead.

(37) "Injection well" means a well into which fluids are being or will be injected, by gravity flow or under pressure.

(38) "Injection well system" means the portion of the disposal system from the effluent side or pressure side of the injection pump to the bottom of the injection well.

(39) "Injection zone" means a geological formation, group of formations, or part of a formation receiving fluids directly through a well.

(40) "Lithology" means the description of rock on the basis of their physical and chemical characteristics.

(41) "Multihorizon monitor well" means any well which is used to monitor in each of two or more discrete zones.

(42) "New injection well" means a well for which a final construction permit has been issued by the Department and which began injection after the effective date of this rule.

(43) "On-site monitor well" means a well associated with an injection well or facility, that is used primarily to monitor the mechanical integrity of the injection well(s) and/or to monitor the effectiveness of the confining beds overlying the injection zone.

(44) "Overdrill" means the amount by which the nominal diameter of the open hole exceeds the diameter of the casing to be set in the hole.

(45) "Owner" means the person, entity, or corporation with legal title to the property on which an injection well exists.

(46) "Packer" means a device lowered into a well to produce a fluid-tight seal.

(47) "Permittee" means the person or entity to which a permit for an injection well or injection well system is issued by the Department. Upon transfer of ownership of the facility, the permittee shall comply with Rule 17-4.12, FAC.

(48) "Plugging" means the act or process of stopping the flow of water, oil, or gas into or out of a formation through a borehold or well penetrating that formation.

(49) "Radioactive waste" means any waste which contains radioactive material in concentrations which exceed those listed in 10 CFR Part 20, Appendix B, Table II, Column 2.

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(50) "Regional monitor well" means a well used primarily to monitor the distant effects of injection from one or more injection facilities.

(51) "Satellite monitor well" means a well associated with an injection facility that is used primarily to monitor the effects of injection from a single injection well or facility.

(52) "Secretary" means the Secretary of the Department of Environmental Regulation.

(53) "Subsidence" means the lowering of the natural land surface in response to: earth movements; lowering of fluid pressure; removal of underlying supporting material by mining or solution of solids, either artificially or from natural causes; compaction due to wetting (hydrocompaction); oxidation of organic matter in soils; or added load on the land surface.

(54) "Surface casing" means the first string of well casing to be installed in the well.

(55) "Technical Advisory Committee" (TAC) means a group of professionals knowledgeable in underground injection control requirements, geology, ground water hydrology, well drilling, geophysical logging, and pollution control, assembled for the purposes of advising the permitting authority on underground injection projects.

(56) "Test well" means the first injection well constructed in a well field, which is used for specific formation testing and to prove the feasibility of the injection well system. A test well is designed to be used as an injection well, if injection is proven feasible and environmentally acceptable.

(57) "Tubing" means piping material placed inside the final string of casing to protect the casing and to convey the injected fluid to the injection zone.

(58) "Underground sources of drinking water" means an "aquifer" or its portion:

(a) 1. Which supplies drinking water for human consumption; or

2. Which is classified by Rule 17-3.403, FAC, as Class G-I or G-II waters; and

(b) Which is not an "exempted aquifer."

(59) "Well" means a bored, drilled or driven shaft, or a dug hole, which has a depth greater than the diameter of the largest surface dimension.

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(60) "Well casing" means a metallic or non-metallic pipe installed in a borehole to prevent caving, provide structural strength, seal off subsurface zones, or prevent the interchange of waters between aquifers.

(61) "Well injection" means the subsurface emplacement of fluids through a well by gravity flow or under pressure.

(62) "Well log" means a record obtained from a well that provides data on the formations penetrated or well construction.

(63) "Well monitoring" means the measurement, by on-site instruments or laboratory methods, of the physical, chemical, or biological parameters required to evaluate the performance of an injection well system.

(64) "Well plug" means a watertight and gastight seal installed in a borehole or well to prevent movement of fluids.

(65) "Well record" means a concise statement of the available data regarding a well.

(66) "Well stimulation" means any of several processes used to clean the well bore, enlarge channels, and increase pore space in the interval to be injected thus making it possible for injected fluids to move more readily into the formation, and includes but is not limited to (1) surging, (2) jetting, (3) blasting, (4) acidizing, (5) hydraulic fracturing.

Specific Authority: 373.309, 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 373.308, 403.021, 403.031, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

17-28.13 General Provisions.

(1) Classification of injection wells. Injection wells are classified as follows:

(a) Class I.

1. Wells used by generators of hazardous wastes or owners or operators of hazardous waste management facilities to inject hazardous waste beneath the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water.

2. Other industrial and municipal (publicly or privately owned) disposal wells which inject fluids beneath the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water.

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(b) Class II. Wells which inject fluids:

1. Which are brought to the surface in connection with conventional oil or natural gas production, and may be commingled with waste waters from gas plants which are an integral part of production operations, unless those waters are classified as a hazardous waste at the time of injection.

2. For enhanced recovery of oil or natural gas; and

3. For storage of hydrocarbons which are liquid at standard temperature and pressure.

(c) Class III. Wells which inject for extraction of minerals, including:

1. Mining of sulfur by the Frasch process;

2. Solution mining of minerals: (Note - Solution mining of minerals includes sodium chloride, potash, phosphate, copper, uranium and any other mineral which can be mined by this process).

(d) Class IV. Wells used by generators of hazardous wastes or of radioactive wastes, by owners or operators of hazardous waste management facilities, or by owners or operators of radioactive waste disposal sites to dispose of hazardous wastes or radioactive wastes into or above a formation which, within one quarter mile of the well, contains either an underground source of drinking water or an exempted aquifer.

(e) Class V. Injection wells not included in Class I, II, III, or IV. Class V wells, which are grouped together by expected quality of the injection fluid, include:

1. Group 1

a. Air conditioning return flow wells used to return to any aquifer the water used for heating or cooling. An air conditioning supply well, heat pump, and return flow well used to inject water containing no additives into the same permeable zone from which it was withdrawn constitute a closed loop system;

b. Cooling water return flow wells used to inject water previously used for cooling;

2. Group 2

a. Recharge wells used to replenish, augment, or store water

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in an aquifer;

b. Salt water intrusion barrier wells used to inject water into a fresh water aquifer to prevent the intrusion of salt water into the fresh water;

c. Subsidence control wells (not used for the purpose of oil or natural gas production) used to inject fluids into a zone which does not produce oil or gas to reduce or eliminate subsidence associated with the overdraft of fresh water;

d. Connector wells used to connect two aquifers to allow interchange of water between those aquifers;

3. Group 3

a. Wells which are part of domestic waste treatment systems;

b. Swimming pool drainage wells;

c. Devices receiving wastes, which have an open bottom and sometimes have perforated sides. This rule does not apply to single family residential waste disposal systems;

d. Wells used to inject spent brine into the same formation from which it was withdrawn after extraction of halogens or their salts;

e. Injection wells used in experimental technologies;

4. Group 4

a. Dry wells used for the injection of wastes into a subsurface formation;

b. Sand backfill wells used to inject a mixture of water and sand, tailing, or other solids into mined out portions of subsurface mines;

c. Wells other than Class IV used to inject radioactive waste, provided the concentrations of the waste do not exceed drinking water standards contained in Chapter 17-22, FAC;

d. Injection wells used for in situ recovery of phosphate, uraniferous sandstone, clay, sand, and other minerals extracted by the borehole slurry mining method;

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5. Group 5

   a. Drainage wells used to drain surface fluid, primarily storm run-off or lake level, (by gravity flow) into a subsurface formation;

6. Group 6

   a. Injection wells associated with the recovery of geothermal energy for heating, aquaculture and electric power;

   b. Other wells.

(2) Identification of Underground Sources of Drinking Water. The Department will identify by narrative description, illustrations, maps, and other means and shall protect, except where exempted under Rule 17-28.13(3), FAC, as an underground source of drinking water, all aquifers or parts of aquifers which meet the definition of an "underground source of drinking water" in Rule 17-28.12(58), FAC. Even if an aquifer has not been specifically identified by the Department, it is an underground source of drinking water if it meets the definition in Rule 17-28.12(58), FAC, and the criteria in Rule 17-3.403, FAC.

(3) Identification of and Criteria for Exempted Aquifers.

(a) After notice and opportunity for a public hearing as provided by Rule 17-3.403, FAC, the Department may identify (by narrative description, illustrations, maps, or other means) and describe in geographic and/or geometric terms (such as vertical and lateral limits and gradient) which are clear and definite, all aquifers or parts thereof which the Department proposes to designate as exempted aquifers using the criteria in Section (c) below. No such designation shall be final until approved by the United States Environmental Protection Agency as part of the State program.

(b) Subsequent to program approval, the Department may, after notice and opportunity for a public hearing, identify additional exempted aquifers. Exemption of aquifers identified under (c)2. below shall be treated as a program revision. Exemption of aquifers identified under (c)3. below shall become final if the Department submits the exemption in writing to the Environmental Protection Agency Administrator and the Administrator has not disapproved the designation within 45 days. Any disapproval by the Administrator shall state the reasons and shall constitute final Environmental Protection Agency action for purposes of judicial review.

(c) An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in Rule 17-28.12(58)(a), FAC, may be determined under Rule 17-28.13(3), FAC, to be an "exempted

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aquifer" if it meets the following criteria:

1. It does not currently serve as a source of drinking water; and

2. It cannot now and will not in the future serve as a source of drinking water because:

a. It is mineral, hydrocarbon, or geothermal energy producing, or can be demonstrated by a permit applicant for a Class III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible;

b. It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

c. It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

d. It is located over a Class III well mining area subject to subsidence or catastrophic collapse.

3. The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to be or become a supply of drinking water.

(d) For Class III wells, the Department shall require an applicant for a permit which necessitates an aquifer exemption under (c)2.a. above to furnish the data necessary to demonstrate that the aquifer is expected to be mineral or hydrocarbon producing. Information contained in the mining plan for the proposed project, such as a map and general description of the mining zone, general information on the mineralogy and geochemistry of the mining zone, analysis of the amenability of the mining zone to the proposed mining method, and a timetable of planned development of the mining zone shall be considered by the Department in addition to the information required by Rule 17-28.33(2), FAC. Approval of the aquifer exemption shall be treated as a program revision.

(4) Area of Review.

(a) An area of review, which shall apply to each Class I and Class III well, well field, project or area of the State, and which may apply to a Class V injection well, shall be determined by the applicant in a manner acceptable to the Department. The manner selected shall take into account the zone of endangering influence, which is the area in which the increased pressures in the injection

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zone may cause the migration of the injected and formation fluid into an underground source of drinking water. The area of review is the land surface overlying the zone of endangering influence.

(b) In determining the area of review, the information to be used shall include, but not be limited to: chemical, physical, and biological characteristics of the injection fluids and formation fluids; hydrogeology; appropriate mathematical models, if available, for computing pressure and concentration changes in the injection zone as a function of distance and time; population; ground water use and dependence; and historical practices in the area. A radius around the injection well of one mile shall be a minimum. In the case of an application for a well field project, a fixed width of not less than one mile for the circumscribing area shall be a minimum.

(5) Corrective Action.

(a) Coverage. Applicants for Class I or Class III injection well permits shall identify, and for any Class V well permit may identify, the location of all known wells within the area of review for that injection well which penetrate the injection zone or confining zone. For such wells which are in use or improperly sealed, completed, or abandoned, the applicant shall also submit a plan consisting of such steps or modifications as are necessary to prevent movement of fluid into underground sources of drinking water ("corrective action"). Where the plan is adequate, the Department shall incorporate it into the permit as a condition. Where the Department's review of an application indicates that the applicant's plan is inadequate (based on the factors in (b)) the Department shall require the applicant to revise the plan, prescribe a plan for corrective action as a condition of the permit under paragraph (b) of this Section, or deny the application.

(b) Criteria and factors. In determining the adequacy of corrective action proposed by the application under (a) of this Section and in determining the additional steps needed to prevent fluid movement into underground sources of drinking water, the following criteria and factors shall be considered by the Department:

1. Nature, volume, and injection rate of the injected fluid;

2. Nature of native fluids, or by-products of injection;

3. Potentially affected population;

4. Geology;

5. Hydrology;

6. History of the injection operation;

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7. Completion and plugging records for all wells;

8. Abandonment procedures in effect at the time the well was abandoned;

9. Hydraulic connections with underground sources of drinking water;

10. Life of injection well; and

11. Pressure considerations.

(c) Requirements.

1. Existing injection wells. Any permit issued for an existing injection well requiring corrective action shall include a compliance schedule requiring any corrective action accepted or prescribed under paragraph (a) of this section. In addition, schedules of compliance shall require compliance not later than three years after the effective date of the permit.

2. New injection wells. No permit for a new injection well may authorize injection until all required corrective action has been completed. The Department shall not authorize construction of a new injection well prior to the completion of all required action unless the applicant can affirmatively demonstrate that such construction will not pose a threat to the quality of the waters of the State.

3. Class III Wells only. When setting corrective action requirements the Department shall consider the overall effect of the project on the hydraulic gradient in potentially affected underground sources of drinking water, and the corresponding changes in potentiometric surface(s) and flow direction(s) rather than the discrete effect of each well. If a decision is made that corrective action is not necessarily based on the determinations above, the monitoring program required in Section 17-28.25(2) shall be designed to verify the validity of such determinations.

(6) Mechanical Integrity.

(a) An injection well has mechanical integrity if:

1. There is no leak in the casing, tubing or packer; and

2. There is no fluid movement into an underground source of drinking water through channels adjacent to the injection well bore.

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(b) One of the following tests shall be used to evaluate the absence of leaks under paragraph (a)1. of this Section.

1. Monitoring of annulus pressure; or

2. Pressure test of inner casing or tubing.

(c) One of the following methods shall be used to determine the absence of fluid movement under paragraph (a)2. of this Section:

1. A temperature or noise log, and monitoring of adjacent overlying aquifers; or

2. A temperature or noise log, monitoring of adjacent overlying aquifers, and radioactive tracer logs.

(d) The Department may allow the use of a test to demonstrate mechanical integrity other than those listed in paragraphs (b) and (c)1. of the Section with the written approval of the United States Environmental Protection Agency.

(e) In conducting and evaluating the tests enumerated in this Section or others to be allowed by the Department, the permittee and the Department shall apply methods and standards generally accepted in the industry. When the permittee reports the results of mechanical integrity tests to the Department, he shall include a description of the test(s) and the method(s) used. In making the evaluation, the Department shall review monitoring and other test data submitted since the previous evaluation.

(f) A permit for any Class I or III well or injection project which lacks mechanical integrity shall include, and for any Class V well may include, a condition prohibiting injection operations until the permittee shows to the satisfaction of the Department under Section 17-28.13(6)(a)-(c) that the well has mechanical integrity or unless the permittee affirmatively demonstrates that the injection well will not pose a potential threat to the waters of the State.

Specific Authority: 373.309, 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

17-28.14 Permit Processing. The time frames in Florida Administrative Code Rule 17-4.055 shall apply to underground injection control permits. However, the failure of the Department to approve or deny a permit for an underground injection well within the 90-day time period shall not result in the automatic approval or denial of the permit and shall not prevent the

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inclusion of specific permit conditions which are necessary to ensure compliance with applicable statutes or rules. If the Department fails to approve or deny such a permit within the 90-day period, the applicant may petition for a writ of mandamus to compel the Department to act consistently with applicable regulatory requirements.

Specific Authority: 373.309, 403.061, 403.087, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.0876, F.S.
History: New 12-3-84.

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PART I: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28.14	Addition	December 3, 1984: Referencing permit processing for underground injection control and incorporating new legislation which provides for no automatic issuance or denial of underground injection control permits if the Department exceeds its 90-day time period; incorporating applicant's right to petition for a writ of mandamus to compel Department to act consistently with applicable regulatory requirements.

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PART I: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28	Amendment	May 8, 1985: Updating rule to conform with U.S. Environmental Protection Agency regulations and to incorporate new technologies and experience with the Underground Injection Control program.
17-28.11(1)-(4)	Amendment	FAW 11/9/739, effective May 8, 1985: Revising references to other rules; excluding from jurisdiction of this rule wells used in conjunction with the operation of an earth-coupled heat pump system as defined in Rule 17-28.12(20).
17-28.12(4)-(66)	Amendment	May 8, 1985: Defining "annular monitor well," "cluster well," "earth-coupled heat pump system," "emergency disposal method," "multihorizon monitor well," "on-site monitor well," "owner," "regional monitor well," "satellite monitor well," "Secretary"; amending width of circumscribing area in "area of review," amending definitions of "exploratory" and "test" wells and "underground sources of drinking water"; renumbering all other definitions.
17-28.13(1)-(4)	Amendment	May 8, 1985: Expanding description of Class II injection wells; revising classification of Class V wells into six separate groups; requiring minimum radius of one mile for area of review around injection well; renumbering and relettering subsections; revising reference numbers.

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PART II: CRITERIA AND STANDARDS FOR CLASS I AND III WELLS

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LISTING OF AMENDMENTS TO PART II

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17-28.20 General Prohibition of Class I Wells Injecting Hazardous Wastes.

(1) The Florida UIC Program shall prohibit the construction of any well meeting the classification in Rule 17-28.13(1)(a)1., FAC, after July 1, 1983.

Specific Authority: 373.309, 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, 403.7222, F.S.
History: New 5-8-85.

17-28.21 Evaluation of Geologic and Hydrologic Environment.

(1) General.

(a) Class I Wells. An applicant for an injection well shall demonstrate to the Department's satisfaction that the hydrogeologic environment is suitable for waste injection without endangering the underground sources of drinking water or modifying the ambient water quality of other aquifers overlying the injection zone. In the Class I well construction permit application, the applicant shall address the proposed testing and sampling procedures for adequately defining the depth at which total dissolved solids exceed 10,000 mg/l in formation waters. An assessment of the lateral position which total dissolved solids exceed 10,000 mg/l in the injection zone waters shall also be provided. The Department may request that the applicant provide, in addition to site specific and area of review information, regional information that will allow prediction of the regional impact of the proposed injection well.

(b) Class III Wells. The Department shall evaluate each proposed mining operation for potential effects of the mining activity on the underground sources of drinking water. The Department shall, at a minimum, consider the effects of depressurization of the aquifer on the water quality of any underground sources of drinking water. An applicant for a Class III injection well project must demonstrate to the Department's satisfaction that the hydrogeologic environment is suitable for injection for extraction of minerals or energy without endangering the underground sources of drinking water. If the applicant can not adequately demonstrate that the the proposed project will not endanger an underground source of drinking water, he must go through the formal procedures for exempting an aquifer

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in Rule 17-28.13(3), FAC.

1. No Class III mining activity shall be allowed in an underground source of drinking water, or shall result in violation of drinking water standards. If the proposed mining activity is in an underground source of drinking water, the formal aquifer exemption procedures must be pursued.

(2) Confining Zone.

(a) Class I Wells. At least one confining zone above the injection zone is required. The applicant shall demonstrate to the Department that the confining zone(s) has sufficient areal extent, thickness, lithologic and hydraulic characteristics to prevent injected fluid migration and that it insures protection of underground sources of drinking water.

(b) Class III Wells. If an underground source of drinking water exists above or below the proposed mining zone, a confining zone is required between the mining zone and the underground source of drinking water. The confining zone must be of such thickness, areal extent, and permeability to constrain the effects of the mining to the mining zone, and the integrity of the confining zone must be maintained for the life of the project.

(c) Testing of Confining Zone for Class I and III Wells. The proposed methodology for testing the confining zone is subject to Department approval. The applicant shall provide sufficient data such as logs, lithologic cores, water samples, and drill stem tests (or aquifer tests) to adequately demonstrate the confining characteristics of the bed. A monitoring system, which may include but not be limited to one or more on-site monitor well(s), designed to evaluate the long-term effectiveness of the confining zone may be required. If the applicant does not propose a monitoring system he shall demonstrate that it is not needed. The geophysical logs may include, but not be limited to:

1. Electric Log
2. Natural Gamma-Ray
3. Fluid Conductance Log
4. Caliper Log
5. Static and Pumping Temperature Log
6. Spinner Flowmeter
7. Acoustic Velocity

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8. Density Log

9. Porosity Log

(3) Injection Zone - Class I Wells. The applicant shall demonstrate to the Department that the proposed injection zone has sufficient extent, thickness, lithologic and hydraulic characteristics to adequately receive waste.

(a) Testing of Injection Zone. The proposed methodology for testing the injection zone is subject to Department approval. The purpose of testing the injection zone is to demonstrate the zone's capacity for receiving injected fluid. The applicant shall demonstrate the suitability of a proposed zone by determining the hydraulic characteristics, lithology, thickness, extent, and compatibility of injection and formation fluids. Testing of the injection zone shall include a pumping injection test at a flow rate of not less than the maximum design capacity of the well, and of such duration that can demonstrate the trend of the injection pressure on the long-term operating conditions. If an adequate water supply for the injection test does not exist, and data collected during drilling strongly indicate the presence of confining bed(s), the applicant may use secondarily treated domestic wastewater effluent for testing only with prior Department approval. Testing of the injection zone may include, but not be limited to:

1. Water Samples

2. Withdrawal Tests

3. Video Television Survey

4. Lithologic Cores

5. Drill Cuttings

6. Geophysical Surveys such as:

a. Electric Survey

b. Natural Gamma-Ray

c. Fluid Conductance Survey

d. Caliper Survey

e. Static and Pumping Temperature Survey

f. Spinner Flowmeter

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g. Acoustic Velocity

h. Focused Resistivity

i. Density Survey

j. Porosity Survey

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721., F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

17-28.22 Well Construction Standards for Class I and III Wells.

(1) General Design Considerations.

(a) All Class I and III wells shall be cased and cemented to prevent the movement of fluids into or between underground sources of drinking water, and to maintain the quality of aquifers above the injection zone that may be used for monitoring or other purposes.

(b) All Class I wells shall be designed and constructed in such a fashion that they inject into a formation which is beneath the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water.

(c) In the design specifications for a Class I well, the applicant shall address the problem of corrosion, proposed protective measure(s), and, if appropriate, proposed methods of monitoring subject to Department approval. The applicant shall consider thickness and type of cement, number and thickness of casings, casing material, casing coatings, formation fluid (water) quality, injection fluid quality and life expectancy of the well.

1. For Class I wells all outer surfaces of uncemented casings or portions of casings shall be coated or otherwise protected against corrosion. This protection shall extend for a minimum distance of thirty feet above and below the uncemented portion of the casing.

(d) All Class I injection wells except those municipal wells (publicly or privately owned) injecting noncorrosive wastes, shall inject fluids through tubing with a packer set immediately above the injection zone, or tubing with an approved fluid seal as an alternative. This requirement shall only apply to wells for which an application for a construction permit has been received by the Department on or after January 16, 1985. Existing wells receiving non-municipal corrosive

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waste through a tubing and packer shall not be allowed to remove the tubing and packer as long as injection of non-municipal corrosive waste continues. The tubing, packer, and fluid seal shall be designed for the expected service.

1. The use of other alternatives to a packer may be allowed with the written approval of the Department. To obtain approval, the applicant shall submit to the Department a written request, which shall set forth the proposed alternative and all technical data supporting its use. The Department shall approve the request if the alternative method will reliably provide a comparable level of protection to underground sources of drinking water.

2. In determining and specifying requirements for tubing, packer, or alternatives, the following factors shall be considered:

a. Depth of setting;

b. Characteristics of injection fluid (chemical content, corrosiveness, and density);

c. Injection pressure;

d. Annular pressure;

e. Rate, temperature and volume of injected fluid; and

f. Size of casing.

(e) For Class I wells the following designs are not allowed:

1. Annuli between casings open to the land surface in any injection well, and

2. Monitoring tubes emplaced and cemented in the annulus adjacent to the innermost or injection string of casing.

(f) For all Class I wells, the applicant shall address potential surge and water hammer protection to protect the safety and integrity of any injection well system.

(g) Department approval is required prior to any remedial procedures that alter the basic design specifications, materials, or character of a Class I or III well.

(2) Exploratory Pilot Hole. The Department may require an exploratory pilot hole in any Class I well, or for Class III wells, at any proposed injection well site, and may require that the hole be drilled in stages. If the applicant does not propose an exploratory pilot hole, he must

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demonstrate that it is not needed.

(3) Drilling. The Department will require that a step-by-step drilling plan be included in the design specifications for Class I and III wells. The drilling plan shall specify the proposed drilling program, sampling, coring, and testing procedures, and is subject to Department approval.

17 [illegible]

(a) For Class I wells, a deviation survey will be run at least every ninety feet (every three joints) of the cased portion of the well and at more frequent intervals when necessary, to ensure that the casing can be set and centered for cementing. The maximum deviation at each measurement shall not exceed one degree deviation from vertical. The Department recognizes that the design requirements in this section may not be necessary in all cases. The Department may modify these requirements in the construction permit provided that the applicant submits proof that such modification will not adversely affect the successful construction and future operation of the well in such a way as to threaten underground sources of drinking water with contamination.

(b) For Class I wells, the Department may require directional surveys, if, after an analysis of the well design and drilling program, it is deemed necessary. The directional survey shall be conducted during drilling or in the pilot hole and the reamed hole as separate surveys before running the casing.

(c) The Department may require the applicant to demonstrate that salt used for density control during drilling will not adversely affect the establishment of background water quality for monitoring purposes.

(4) Casings.

(a) The casings used in the construction of each newly drilled Class I and III well shall be designed for the life expectancy of the well, and shall be new and unused for Class I wells.

(b) The number, thickness, type of materials, and length of casing shall be sufficient to protect the quality of drinking water resources and the integrity of the well and the confining strata. At a minimum, the final string of casing shall be made of seamless mild steel pipe having a 0.500 inch wall thickness. An applicant who proposes to use pipe composed of other than 0.500 inch wall seamless mild steel for the final casing shall demonstrate that the proposed material and thicknesses will not compromise the integrity or operation of the well.

(c) Exact setting depths of all casings shall be determined in the field, based on all available information, and subject to the Department's approval as specified in the construction permit.

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(5) Cementing.

(a) The applicant shall submit the proposed cementing program with the design specifications for Class I or III wells. The cement used in the construction of each newly drilled well shall be designed for the life expectancy of the well. In determining and specifying casing and cement requirements, the following factors shall be considered:

1. Depth to the injection zone;

2. Injection pressure, external pressure, internal pressure, and axial loading;

3. Hole size;

4. Size and grade of all casing strings (wall thickness, diameter, nominal weight, length, joint specification, and construction material);

5. Corrosiveness of injected fluid, formation fluids, and temperatures;

6. Lithology of injection and confining zones; and

7. Type or grade of cement.

(b) Cement must be compatible with the injected fluid, native fluids, and the formation, but in no case less than the quality of American Society of Testing and Materials Type 2 or its equivalent (Standard Specification for Portland Cement, American National Standards Institute/American Society of Testing and Materials C 150-78(a), 1978).

(c) Applicants shall submit with the design specifications, a list of cement additives which may be needed in the operation for Department approval. If an additive is not in the design specifications, the applicant shall obtain prior approval for its use from the Department. Accurate records shall be kept and all additives used shall be reported.

(d) Use of cement additives, water/cement ratio, and the type of water used for mixing shall be determined by the applicant, provided the integrity, containment, corrosion protection, and structural strength of the cement are not significantly affected.

(e) Prior to cementing, the hole shall be conditioned in such a way as to create optimum bonding of the cement to the casing and formation, and to prevent channeling.

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(f) Cement placement shall be in such a manner that the purposes and characteristics of the cement are retained, and shall be subject to Department approval and in accordance with "AWWA Standard for Deep Wells", American Water Well Association A100-66, 1966.

(g) The applicant shall submit his cement testing program with the permit application for Department approval. The purpose of the cement testing program is to insure that the cement seal is adequate to prevent migration of fluids in channels, microannular space, or voids in the cement. The methods of testing which may include, but are not limited to:

1. Pressure testing of the cement plug at the bottom of the casing - to not less than 1.5 times the expected injection pressure or fifty pounds per square inch, whichever is greater;

2. Temperature Survey - must be run within forty-eight hours after cementing;

3. Cement Bond Survey.

(h) During cementing, adequate pressure differentials shall be maintained to prevent collapse or distortion of the casing.

(i) For Class I wells, the final string of casing shall have a nominal overdrill of ten inches unless the applicant can affirmatively demonstrate to the satisfaction of the Department that an overdrill of not less than five inches is sufficient. The annulus surrounding the final string of casing shall have a nominal five inch cement thickness from the bottom of the casing to land surface. The Department recognizes that the design requirements in Rule 17-28.22(5)(i), FAC, may not be necessary in all cases. The Department may modify these requirements in the construction permit provided that the applicant submits proof that such modification will not adversely affect the successful construction and future operation of the well in such a way as to threaten an underground source of drinking water with contamination. The remaining casings must have a minimum thickness of 2 1/2 inches of cement surrounding the casings with not less than five inches of overdrill. A nominal ten inch overdrill shall be required with any intermediate string of casing for which an annular monitor tube of up to 2 3/8 inch maximum outer diameter is to be emplaced. Commensurate increases in the overdrill shall be required for monitor tubes larger than 2 3/8 inches in outer diameter. The applicant shall include with the cementing program a centralizing program for the purpose of centralizing the casing, to provide adequate annular space around the casing for proper cementing.

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(6) Testing During Drilling and Construction of New Class I Wells.

(a) Appropriate geophysical surveys and other tests shall be conducted during the drilling and construction of new Class I wells. A descriptive report interpreting the results of such geophysical surveys and tests shall be presented to the Technical Advisory Committee during in-progress reviews, as part of periodic progress reports, or in letter form as appropriate. Such reports shall include field copies of the surveys and test data and analysis results at the level required to support field decisions made during drilling or proposed during in-progress reviews. At a minimum, such surveys and tests shall include:

1. Deviation checks shall be in accordance with Rule 17-28.22(3), FAC. Such checks shall be at sufficiently frequent intervals to assure that vertical avenues for fluid migration in the form of diverging holes are not created during drilling.

2. Such other geophysical surveys and tests as may be needed after taking into account the availability of similar data in the area of the drilling site, the construction plan, and the need for additional information that may arise from time to time as the construction of the well progresses. In determining which geophysical surveys and tests shall be required, the following geophysical surveys shall be considered for use in the following situations:

a. For surface casing intended to protect underground sources of drinking water:

(I) Resistivity, sonic survey, spontaneous potential, and mechanical or sonar caliper surveys before the casing is installed; and

(II) A cement bond, temperature, or density survey after the casing is set and cemented.

b. For intermediate and long strings of casing intended to facilitate injection:

(I) Resistivity, spontaneous potential, porosity, and gamma ray surveys before the casing is installed;

(II) Fracture finder surveys; and

(III) A cement bond, temperature, or density survey after the casing is set and cemented.

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c. For Class I wells in which an annular monitor tube is proposed for other than the final or innermost casing:

(I) A caliper survey in the reamed hole which is to contain the monitor tube and;

(II) A temperature survey may be required in the monitor tube after the monitor tube has been set and cemented.

(b) The following information concerning the injection formation shall be determined or calculated for new Class I wells:

1. Fluid pressure;

2. Temperature;

3. Fracture pressure;

4. Other physical and chemical characteristics of the injection matrix; and

5. Physical and chemical characteristics of the formation fluids.

(7) Testing Integrity of Completed Class I Wells. Upon completion of construction, the completed wells will be tested to assure that the wells will function as built. Tests to be performed may include, but not be limited to:

(a) Cement Bond Survey;

(b) Temperature Survey;

(c) Pressure test of final casing to at least 1.5 times the expected injection pressure for one hour, with no pressure drop after temperature correction;

(d) Video Television Survey - From top to bottom of the well for baseline monitoring purposes;

(e) Injection tests;

(f) Withdrawal Tests - If necessary and if possible; and

(g) Caliper Survey.

(8) Testing of Class III Wells.

(a) Appropriate geophysical surveys and other tests shall be conducted during the drilling and construction of new Class III wells.

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Upon completion of construction, the completed well system will be tested to assure that the well system will function as designed at the design operation pressures. A descriptive report interpreting the results of such surveys and tests shall be prepared and submitted to the Department. The surveys and tests appropriate to each type of Class III well shall be determined based on the intended function, depth, construction and other characteristics of the well, availability of similar data in the area of the drilling site and the need for additional information that may arise from time to time as the construction of the well progresses. At a minimum, such surveys and tests shall include deviation checks conducted on all holes where pilot holes and reaming are used, at sufficiently frequent intervals to assure that vertical avenues for fluid migration in the form of diverging holes are not created during drilling.

(b) Where the injection zone is a water bearing formation, the following information concerning the injection zone shall be determined or calculated for new Class III wells:

1. Fluid pressure;

2. Temperature;

3. Fracture pressure;

4. Other physical and chemical characteristics of the injection zone;

5. Physical and chemical characteristics of the formation fluids; and

6. Compatibility of injected fluids with formation fluids.

(c) Where the injection formation is not a water bearing formation, the information in paragraph ^{1}(b)(3) and (b)(4) of this section must be submitted.

(9) Environmental Concerns During Construction.

(a) For Class I and III wells, the disposal of drilling fluids or cuttings and the disposal of formation water or waste during testing shall be in a sound environmental manner that avoids violation of surface and ground water quality standards. The proposed disposal method must be approved by the Department prior to start of construction.

(b) For Class I wells the use of drilling pads will be required. The pads will be designed to collect spillage of contaminants and to support the heaviest load that will be encountered during drilling. At locations where the unconfined aquifer contains less than 10,000

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mg/l total dissolved solids, monitor wells capable of detecting any contamination of the unconfined aquifer from drilling activities shall be required.

(c) For Class I wells, flow control shall be used when drilling into formations in which pressure heads exceed land surface, to prevent uncontrolled release of formation or drilling fluids at land surface.

(d) For Class III wells, the applicant is advised that other permits may be required for surface facilities associated with the mining activity.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

[1] **REGfile-system Editor's Note:** Reference to paragraphs (b)(3) and (b)(4) should be (b)3. and (b)4., respectively.

17-28.23 Operating Requirements for Class I and III Wells.

(1) Class I Well Operating Requirements. Operating requirements for Class I wells shall, at a minimum, specify that:

(a) To preserve the integrity of the formations, bottom hole (including hydrostatic) pressure shall not exceed a maximum so as to insure that the injection pressure does not initiate new fractures or propagate existing fractures in the injection zone, initiate fractures in the confining zone, significantly alter the fluid movement capabilities of the confining zone, or cause the movement of injection or formation fluids into an underground source of drinking water or into an essential monitoring zone;

(b) To protect the integrity of the well structure, total pressure shall not exceed the maximum allowable stress of the materials used to construct the well;

(c) Injection for disposal purposes is prohibited:

1. Between the outermost casing protecting the underground sources of drinking water and the well bore;

2. Through annular monitor tubes, and;

3. Through wells designed to monitor the injection zone except when specifically designed as a temporary injection well or approved (in writing) for emergency discharge use.

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(d) Unless an alternative to a packer has been approved under Rule 17-28.22(1)(d)1., FAC, the annulus between the tubing, where required, and the final or innermost string of casing shall be filled with a fluid and a pressure shall be maintained on the annulus. Both the type of fluid and the proposed pressure shall be approved by the Department;

(e) The maximum velocity of injected fluid shall not exceed the point where the mechanical limits of the well design or structure of the formation will be adversely affected. The maximum injection velocity of a well that begins operation after June 1, 1985 shall not exceed eight ft/sec (feet per second), unless the applicant can prove to the satisfaction of the Department that higher velocities will not compromise the integrity or operation of the well.

(2) Class III Well Operating Requirements. Operating requirements prescribed for Class III wells shall, at a minimum, specify that:

(a) Injection pressure at the wellhead shall not exceed a maximum which shall be calculated so as to assure that the pressure in the injection zone during injection does not initiate new fractures in the confining zone or cause the migration of injection or formation fluids into an underground source of drinking water; and

(b) Injection between the outermost casing protecting underground sources of drinking water and the well bore is prohibited;

(c) Where the proposed mining operation includes mining a portion of the confining zone, a sufficient amount of confining zone must remain to provide an effective confinement that protects aquifers above and below the mining area.

(3) Operation and Maintenance Manual.

(a) An operation and maintenance manual(s) for injection well disposal facilities, or portions thereof, shall be prepared for the use of operators, maintenance personnel, technicians, laboratory personnel and others, as appropriate, and shall consist of:

1. Written instructions provided to the injection system operators for the safe reliable operation of the system;

2. Records of the basic engineering design and equipment description;

3. A program to assure proper maintenance of the system.

(b) The operation and maintenance manual(s) is subject to approval by the Department under Section 17-4.22 F.A.C. prior to issuance of a permit and shall be submitted to the Department upon request.

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(c) A copy of the approved manual shall be provided to the operators, maintenance personnel, technicians, laboratory personnel and others, as appropriate, by the permittee of the facility. The manual(s) shall be available for reference at the facility or other approved site.

(d) The Department may require revisions to the manual to reflect any facility modifications performed in order to comply with the requirements of this Chapter, or to reflect experience resulting from facility operation.

(4) Abnormal Events.

(a) In the event the permittee is temporarily unable to comply with any of the conditions of a permit, due to breakdown of equipment, power outages, destruction by hazard of fire, wind, or by other cause, the permittee of the facility shall notify the Department. Notification shall be made in person, by telephone, or by telegraph to the nearest office of the Department within 24 hours of breakdown or malfunction.

(b) A report shall be required by the appropriate district office within 72 hours of the notification referenced in (a), above. A final written report shall be submitted within two weeks and shall describe the nature and cause of the breakdown or malfunction, the steps being taken or planned to be taken to correct the problem and prevent its reoccurrence, emergency procedures in use pending correction of the problem, and the time when the facility will again be operating in accordance with permit conditions.

(c) Under emergency conditions in which the permittee is unable to use the permitted primary disposal method, the permittee may use an emergency discharge only if prior Department approval of the emergency method has been obtained. The applicant shall address the emergency disposal methods in the construction permit application and the operating manual.

(d) In the event a well must be redeveloped, the applicant shall address disposal of backwashed fluids. The disposal method shall be approved by the Department.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

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17-28.24 Monitoring Well Construction Standards for Class I and III Wells.

(1) General Design Considerations.

(a) For Class I wells, associated on-site, cluster, multihorizon, or annular monitoring wells shall not penetrate the injection zone or final confining bed.

(b) For satellite and regional monitor wells associated with Class I wells, cluster or multihorizon monitoring wells may penetrate the injection zone or final confining bed only if the applicant can demonstrate that the underground sources of drinking water and confining strata will be protected, the integrity of the monitoring and injection well system will be protected, and the well is designed in such a way that it can be easily repaired.

(c) All monitoring wells constructed for Class III injection operations shall be constructed in accordance with Chapter 17-21, FAC.

(d) Department approval is required prior to any remedial procedures that alter the basic design specifications.

(2) Exploratory Pilot Hole. For Class I wells, the Department may require an exploratory pilot hole and may require that the hole be drilled in stages. If the applicant does not propose an exploratory pilot hole, he must demonstrate that it is not needed for logging or other purposes.

(3) Drilling. The Department shall require that a step-by-step drilling plan be submitted with the design specifications.

(4) Casings and Tubing.

(a) The casings or tubing used in the construction of each newly drilled well shall be designed for the life expectancy of the well.

(b) The number, thickness, type of material, and length of casing or tubing shall be sufficient to protect the quality of drinking water resources and the integrity of the well and the confining strata. The type of materials used in the monitoring well shall not bias the sampling parameters used in the monitoring program.

(c) Exact setting depths for all casings or tubing shall be determined in the field, based on all available information, and subject to the Department's prior approval.

(5) Cementing.

(a) The applicant shall submit the proposed cementing program with

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the design specifications. The cement used in the construction of each newly drilled well shall be designed for the life expectancy of the well. The applicant shall submit a list of proposed additives for Department approval.

(b) Cement must be compatible with the native fluids and the formation, but in no case less than the quality of American Society for Testing and Materials Type 2 or its equivalent (Standard Specification for Portland Cement, American National Standards Institute/American Society for Testing and Materials C 150-78(a), 1978).

(c) Cement placement shall be in such a manner that the purposes and characteristics of the cement are retained, and shall be subject to Department approval and in accordance with "AWWA Standard for Deep Wells", American Water Well Association A100-66, 1966.

(d) The applicant shall submit his cement testing program with the permit application for Department approval.

(e) For Class I monitor wells other than annular monitor wells, a nominal thickness of 2-1/2 inches of cement surrounding the casings with not less than five inches of overdrill is required, except for the annulus being used for monitoring in wells with open annulus monitoring.

(f) All casings and tubing shall be centralized where possible to ensure uniform cementing.

(g) All outer surfaces of casing or tubing which are uncemented shall be protected from corrosion for a minimum of thirty feet above and below the uncemented portion.

(6) Testing of Monitoring Well Construction. Tests may include but not be limited to:

(a) Cement Bond Survey.

(b) Temperature Survey.

(c) Pressure test to at least 1.5 times the expected ultimate monitoring pressure but not less than 50 pounds per square inch for one hour, with no pressure drop after temperature correction.

(d) A pumping test to determine if the monitor well has sufficient capacity to yield a representative ground water sample.

(e) Chemical analyses of water from strata tapped by well.

(f) Water level measurement referenced to mean sea level.

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Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, 5-8-85.

17-28.25 Monitoring Requirements for Class I and III Wells.

(1) Class I Wells. For Class I wells, monitoring requirements shall, at a minimum, include:

(a) The analysis of the injected fluids at a frequency specified in the operating permit to yield representative data on their characteristics;

(b) The installation and use of continuous indicating, recording, and totalizing devices to monitor flow rate and volume, and installation and use of continuous indicating and recording devices to monitor the injection pressure and the pressure on the annulus between the tubing and the final or innermost string of casing, if there is an annulus;

1. The Department may periodically require a controlled injection test or a bottom hole pressure survey, if a long-term trend of increasing injection pressure is indicated.

(c) A demonstration of mechanical integrity pursuant to Rule 17-28.13(6), FAC, at least once every five years during the life of the well; and

1. As part of the baseline monitoring information, a video television survey from the surface to the bottom of the injection zone shall be run prior to injection but after completion of testing, except for those wells that inject through tubing or where it is physically impossible to do so, and every five years thereafter, or more frequently if deemed necessary by the Department.

2. The television survey may be either black and white or color.

3. Adequate provisions must be made to centralize the camera in the borehole.

4. Before running the survey, adequate provisions shall be made to assure that fluid in both the casing and open borehole is of sufficient clarity to provide a baseline survey of a quality acceptable to the Department.

(d) Within the area of review, the type, number, and location of well(s) to be used to monitor any potential migration of fluids into or in the direction of underground sources of drinking water, and

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pressure in the underground sources of drinking water; the parameters to be measured and the frequency of monitoring shall be stated in the application for the construction permit.

(e) The background water quality of the injection zone and the monitoring zone(s) shall be determined prior to injection for both domestic wastewater wells and industrial Class I wells (including reverse osmosis reject water), in accordance with the sampling and testing methods outlined in Rule 17-19.04, FAC.

1. Background levels shall be determined pursuant to the following criteria:

a. For monitor zones in Class G-I, G-II or G-III ground waters the primary and secondary drinking water quality parameters listed in Rule 17-22.104, FAC, and the minimum criteria provided in Rule 17-3.402, FAC.

b. For the injection zone and monitor zones in G-IV ground water the criteria shall be established on a case by case basis.

(f) The Department shall require monitor well(s) above the injection zone near the injection well, field or project.

1. The permittee shall be able to monitor the following:

a. The absence of fluid movement adjacent to the well bore as required in Rule 17-28.13(6), FAC, and;

b. The long-term effectiveness of the confining zone.

(g) The Department may require monitor wells above and in the injection zone at a sufficient distance from the well, field or project for regional monitoring.

(h) For Class I wells, a five gallon unacidized representative sample of native water from the injection zone shall where practical be collected and provided to the Florida Department of Environmental Regulation, 2600 Blair Stone Road, Tallahassee, Florida 32301 or a laboratory specified by the Department.

(i) Post-closure monitoring. For Class I wells, the permit applicant may be required to submit a post-closure monitoring plan designed to monitor the attenuation of any pressure effects and water quality changes caused by the underground injection operation both in the injection zone and/or in overlying aquifers. The proposed monitoring plan shall at a minimum utilize the injection wells and associated monitor wells, to the extent that they are capable of yielding representative ground water samples. The proposed monitoring plan may also include other accessible wells.

1. Items to be addressed by the permit applicant in the proposed post-closure monitoring plan shall include, but not be limited to:

a. Designation of the wells to be used for post-closure monitoring;

b. The parameters to be monitored, by well;

c. The sampling frequency;

d. The proposed duration of the post-closure monitoring period; and

e. A documented estimate of the total cost of the post-closure monitoring program.

2. A revision of the post-closure monitoring plan may be required by the Department, when appropriate, in order to reflect changes in the design or scope of the underground injection operation, inflation of costs associated with the plan, or other factors resulting from the construction or operation of the injection well system. The permittee also may initiate modification of the post-closure monitoring plan, subject to Department approval.

(2) Class III Wells. For Class III wells, monitoring requirements shall, at a minimum, specify:

(a) The analyses of the physical and chemical characteristics of the injected fluid with sufficient frequency to yield representative data on its characteristics;

(b) Installation and use of continuous recording devices to monitor the injection pressure, flow rate and volume;

(c) The demonstration of mechanical integrity pursuant to Section 17-28.13(6) at least once every five years during the life of the well;

(d) Weekly monitoring of fluid level and of the parameters chosen to measure water quality in the injection zone with sufficient frequency to yield representative data on its characteristics;

(e) Quarterly monitoring of wells adjacent to the injection site to detect any migration from the injection zone into an underground source of drinking water;

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(f) All Class III wells may be monitored on a field or project basis rather than an individual well basis by manifold monitoring. Manifold monitoring may be used in cases of facilities consisting of more than one injection well operating with a common manifold. Separate monitoring systems for each well are not required provided the owner/operator demonstrates that manifold monitoring is comparable to individual well monitoring;

(g) The Department may require that the applicant monitor for a period of time after mining operations cease. If the monitoring reveals violations, the permittee must investigate and take corrective action.

^{1}(i) Monitoring Criteria.

1. Where injection is into a formation which contains water with less than 10,000 mg/1 total dissolved solids, monitoring wells shall be completed into the injection zone and into any underground sources of drinking water above, and may be required below, the injection zone which could be affected by the mining operation. These wells shall be located in such a fashion as to detect any excursion of injected fluids, process by-products, or formation fluids outside the mining area or zone. If the operation may be affected by subsidence or catastrophic collapse, the monitoring wells shall be located so that they will not be physically affected.

2. Where injection is into a formation which does not contain water with less than 10,000 mg/1 total dissolved solids, monitoring wells may be required above and in the injection zone.

3. Where the injection wells penetrate an underground source of drinking water in an area subject to subsidence or catastrophic collapse an adequate number of monitoring wells shall be completed into the underground source of drinking water to detect any movement of injected fluids, process by-products or formation fluids into the underground source of drinking water. The monitoring wells shall be located outside the physical influence of the subsidence or catastrophic collapse.

4. The Department may require monitoring for subsidence.

^{1}(j) In determining the number, location, construction and frequency of monitoring of the monitoring wells the following criteria shall be considered:

1. The population relying on the underground source of drinking water affected or potentially affected by the injection operation;

2. The proximity of the injection operation to points of with-

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drawal of drinking water;

3. The local geology and hydrology;

4. The operating pressures and whether a negative pressure gradient is being maintained;

5. The toxicity and volume of the injected fluid, the formation water, and the process by-products; and

6. Number of injection wells per unit area.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

[1] **REGfile-system Editor's Note:** Paragraphs (i) and (j) should have been titled (h) and (i), respectively.

17-28.26 Reporting Requirements for Class I and III Wells.

(1) Class I Exploratory Well Construction Permit and Class I Test/Injection Well Construction Permit.

(a) The Department may require periodic data reports and progress reports that may include, but not be limited to, the following:

1. Driller's log

2. Geophysical surveys

3. Core analyses

4. Lithologic Logs

5. Drill stem tests

6. Pump tests

7. Daily job (construction) reports

8. Water quality analyses.

(b) The frequency of reporting shall be specified in the individual permit.

(c) Interpretation of data is required in the data reports or progress reports at the completion of each significant phase of construc-

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tion, such as completion of test well construction and testing, completion of injection well construction, and completion of injection well testing.

(d) The Department may request that the applicant provide direct distribution of the data reports, progress reports, and final reports to members of the Technical Advisory Committee.

(e) The applicant shall submit final reports of all data collected from the exploratory well with interpretations, to the Department with the application for a Class I Test/Injection Well Construction and Testing Permit and a Class I Injection Well Operation Permit. The Final Report submitted with the application for an Class I Injection Well Operation Permit shall include, but not be limited to, all information and data collected under Rules 17-28.33(2) and 17-28.33(3), FAC, with appropriate interpretations.

(2) Class I Injection Well Operating Permit.

(a) The applicant must submit, for Department approval, the proposed methodology for collection and reporting of operational data, to ensure that the data is collected, correlated, and reported in a fashion that would enable the agency to evaluate well performance.

(b) Reporting requirements shall be in accord with Chapter 17-19, FAC, where applicable. The frequency of reporting shall be specified in the individual permits, and at a minimum include:

1. Operating reports to the Department on:

a. The physical, chemical and other relevant characteristics of injection fluids;

b. Daily readings of the pressure and flow for each well shall be submitted. For each domestic effluent disposal well, a specific injectivity test shall be performed quarterly while the pumping rate to the well(s) has been set at a predetermined level and reported as the specific injectivity index (gpm/specific pressure (psig)). The applicant shall propose which pumping rate will be used based on the expected flow, the design of the pump station including the volume of the wet well and pump type(s), and the type of pump controls used.

c. Monthly average, maximum and minimum values for injection pressure, flow rate and volume, and annular pressure; and

d. The results of monitoring prescribed under Rule 17-28.25(1)(d), FAC.

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2. Reporting the results, within three months after the completion of:

a. Periodic tests of mechanical integrity;

b. Any other test of the injection well conducted by the permittee if required by the Department; and

c. Any well work over.

(c) The Department may require additional data to be submitted with the periodic operations reports, the content and frequency of which are specified in the individual permit.

(d) A Class I well operating permit shall be written to require that if Rule 17-28.13(5)(c)1., FAC, is applicable, progress reports shall be submitted no later than thirty days following each interim date and the final date of compliance.

(3) Class III Well Construction/Operating/Plugging and Abandonment Permit.

(a) The permitting agency may require periodic data reports and progress reports that may include, but not be limited to, the following:

1. Driller's log

2. Geophysical surveys

3. Core analyses

4. Lithologic Logs

5. Drill stem tests

6. Withdrawal or aquifer tests

7. Number of wells constructed, abandoned, in operation, and recorded on property deeds

8. Results of post-closure monitoring

9. Daily construction reports

(b) The frequency of reporting shall be specified in the individual permit. However, the applicant may be required to submit monthly operating reports that shall include but not be limited to, the number of wells constructed, number in operation, number abandoned, and number of wells recorded on property deeds for that month.

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(c) Interpretation of data is required in the data reports or progress reports at the completion of each significant phase of construction.

(d) The permitting authority may request that the applicant provide direct distribution of the data reports and progress reports to members of the Technical Advisory Committee.

(e) Reporting Requirements. Reporting requirements shall, at a minimum include:

1. Quarterly reporting to the Department on required monitoring;

2. Results of mechanical integrity and any other periodic test required by the Department reported with the first regular quarterly report after the completion of the test; and

3. The Department may require that monitoring be reported on a project or field basis rather than individual well basis.

(f) At least once every year, but more frequently if specified in the permit, the applicant shall record the plugging method and location of each abandoned well abandoned during that year with the property records of the county courthouse.

(g) The applicant shall submit a Final Report of all data collected with interpretations, to the permitting authority with the application for permit renewal. The Final Report shall include, but not be limited to all information and data collected under Section 17-28.33(2) and (3), with appropriate interpretations.

(4) Abandonment Reports for Class I and III Wells.

(a) Upon completion of plugging and abandonment of a well or well field the permittee shall submit to the Department a Final Report which includes, but is not limited to, the following:

1. Certification of completion in accordance with approved plans and specifications by the engineer of record;

2. Evidence, such as a sealed copy or certification from the county clerk, that a surveyor's plot of the location of the abandoned wells has been recorded in the county courthouse property records.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

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17-28.27 Plugging and Abandonment Criteria and Procedures for Class I and III Wells.

(1) The Department may order a well plugged when it has been abandoned or when it is determined to be a threat to the waters of the State.

(2) Any Class I or III permit shall include conditions to ensure that plugging and abandonment of the well will not allow the movement of fluids either into an underground source of drinking water or from one underground source of drinking water to another. Any applicant for an Underground Injection Control permit shall be required to submit a plan for plugging and abandonment, which may include post-closure monitoring of the injection operation. The post-closure monitoring plan shall be designed in accordance with the requirements of Rule 17-28.25(1)(i), FAC. Where the plan meets the requirements of this Rule, the Department shall incorporate it into the permit as a condition. Where the Department's review of an application indicates that the permittee's plan is inadequate, the Department shall require the applicant to revise the plan, prescribe conditions meeting the requirements of this Rule, or deny the application. For purposes of this Rule, temporary intermittent cessation of injection operations is not abandonment. Where applicable, the plugging and abandonment plan shall address the proposed post-closure monitoring.

(3) Prior to abandoning Class I or III wells the well shall be plugged with cement in a manner which will not allow the movement of fluids either into or between underground sources of drinking water. The Department may allow Class III wells to use other plugging materials if it is satisfied that such materials will prevent movement of fluids into or between underground sources of drinking water. The proposed plugging method and type of plugging material shall be approved in writing by the Department.

(4) Placement of the plugging material shall be accomplished by one of the following methods:

(a) The Balance Method;

(b) The Dump Bailer Method;

(c) The Two-Plug Method; or

(d) Any other recognized method as effective or more effective than the above which is approved in writing by the Department on a case by case basis.

(5) The well to be abandoned shall be in a state of static equilibrium with the mud weight equalized from top to bottom, either by circulating the mud in the well at least once or by a comparable method prescribed

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by the Department, prior to the placement of the cement plug(s).

(6) The permittee shall notify the Department at least 180 days before conversion or abandonment of a Class I well, unless abandonment within a lesser period of time is necessary to protect the waters of the State.

(7) For all Class I wells, the final or innermost string of casing shall be filled with neat cement grout or an approved equivalent from the bottom of the casing to the surface. The Department may require or allow the use of other fillers in the open hole provided that the objectives of confining injected fluids to the injection horizon and prevention of migration of injected and/or native fluids between aquifers are satisfied. Annular monitor tubes in an injection well may be left unplugged temporarily if they are to be used for their intended purpose and do not compromise the objectives listed above. If temporarily left open, the annular monitor tubes shall, after Department approval, be plugged with cement at the end of post-closure monitoring. If the tubes are not used for monitoring, they shall be filled with neat cement from the bottom of the monitor zone to land surface.

(8) The plugging and abandonment plan required in Rules 17-28.27 and 17-28.35, FAC, shall, in the case of a Class III well field which underlies or is in an aquifer which has been exempted under Rule 17-28.13(3), FAC, also demonstrate that no movement of contaminants from the mined zone into an underground source of drinking water will occur. The Department shall prescribe aquifer cleanup and monitoring where deemed necessary and feasible to insure that no migration of contaminants from the mined zone into an underground source of drinking water will occur.

(9) Financial responsibility. The permit shall require the permittee to maintain financial responsibility and resources, in the form of performance bonds or other equivalent form of financial assurance approved by the Department, to close, plug, and abandon the underground injection operation in a manner prescribed by the Department. In lieu of individual performance bonds, the applicant may furnish a bond or other equivalent form of financial guarantee approved by the Department covering all his injection wells in this State. The Department may require a certificate that the applicant has assured, through a performance bond or other appropriate means, the resources necessary to cover post-closure monitoring and any corrective action resulting from this monitoring.

(10) In the event a radioactive source tool has been irretrievably lost down an injection well, the Department shall be immediately notified. The well shall not be plugged until all applicable Nuclear Regulatory Commission regulations have been satisfied.

(11) The owner/operator of a well must provide adequate documentation that the well was properly abandoned.

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Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

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PART II: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28.20(1)	Addition	May 8, 1985: Authorizing Florida UIC Program to prohibit construction of any well meeting classification in Rule 17-28.13(1)(a)1., FAC, after July 1, 1983.
17-28.21(1)-(3)	Amendment	May 8, 1985: Strengthening requirements for testing and sampling procedures, including institution of monitoring system unless applicant can demonstrate it is not needed; allowing secondarily treated domestic wastewater effluent for testing only with prior Department approval.
17-28.22(1), (3)-(6), (9)	Amendment	May 8, 1985: Expanding construction and monitoring standards for Class I and Class III wells; disallowing certain designs for Class I wells; incorporating new technology of annular monitoring; requiring monitor wells for certain unconfined aquifers and flow control in certain situations.
17-28.23(1),(4)	Amendment	May 8, 1985: Specifying prohibitions of injection for disposal purposes; setting maximum injection velocities; requiring prior approval for emergency disposal methods.
17-28.24(1),(4)	Amendment	May 8, 1985: Strengthening monitoring well construction standards for Class I wells; requiring demonstration that underground sources of drinking water and confining strata will be protected; setting new casing and testing requirements.
17-28.25(1)	Amendment	May 8, 1985: Changing description of string of casing from "long" to "final or innermost"; setting new requirements for television survey, determination of background water quality levels, and use of monitor wells; requiring, where practical, sample of native water; setting standards for post-closure monitoring.

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PART II: LISTING OF AMENDMENTS

17-28.26(1),(2)	Amendment	May 8, 1985: Including water quality analyses in data and progress reports; specifying for each domestic effluent disposal well a quarterly specific injectivity test.
17-28.27(2), (7)-(11)	Amendment	May 8, 1985: Requiring post-closure monitoring plan be designed in accordance with requirements of Rule 17-28.25(1)(i); allowing annular monitor tubes to be left open under certain conditions; requiring immediate notification to Department if radioactive source tool is lost down well.

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LISTING OF AMENDMENTS TO PART III

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PART III: CLASS I AND III WELL PERMITTING

17-28.31 General.

(1) Permitting Authority. The Florida Department of Environmental Regulation is the administering agency for the underground injection control rule and requires permits for all Class I and III wells. However, this does not absolve the permittee from obtaining permits, where necessary, from other state agencies, water management districts, or local programs nor relieve the permittee of the responsibility for obtaining such permits.

(2) General Prohibitions.

(a) Effective no later than the effective date of this rule, any underground injection through a Class I or III well is prohibited, except as authorized by permit.

1. Permits for any construction, modification, operation (except for testing purposes as authorized by the construction permit), or abandonment of Class I and III wells shall be obtained before such activities are commenced.

(b) No underground injection control permit or rule shall be authorized where a Class I or III well causes or allows movement of fluid into underground sources of drinking water.

(c) For Class I and III wells, if any monitoring indicates the movement of injection or formation fluids into underground sources of drinking water, the Department shall prescribe such additional requirements for construction, corrective action (including closure of the injection well), operation, monitoring, or reporting as are necessary to prevent such movement. These additional requirements shall be imposed by modifying the permit, or the permit may be terminated if cause exists, or appropriate enforcement action may be taken if the permit has been violated.

(3) Duration. All Department permits shall expire five years from the date of issuance except that an earlier expiration date may be specified by the Department; however, construction permits shall be issued for a period of time as necessary.

(4) Application for Permit.

(a) The applicant shall submit application for permits on forms provided by the Department and shall include:

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PART III: CLASS I AND III WELL PERMITTING

1. The application form properly completed and signed;

2. Information as required in Rules 17-28.32 through 17-28.35, FAC;

3. Such additional information as may be necessary to properly evaluate the application;

4. The appropriate fee as specified in Rule 17-4.05(4), FAC.

(b) A minimum of four copies of the application package shall be submitted to the Department. Additional copies may be required as necessary to provide copies to members of the Technical Advisory Committee. Direct distribution to the Technical Advisory Committee may be required.

(c) Any person who performs or proposes an underground injection for which a permit is required shall submit an application to the Department as follows:

1. For existing Class I or III wells, when the current facility permit issued by the Department expires, but no later than five years from the effective date of this rule or as required by Rule 17-28.42, FAC, for wells injecting hazardous wastes.

2. For new Class I or III wells, not less than 90 days before construction is expected to begin.

(d) For Class III well fields or projects, the owner may apply for a single permit for the well field, provided all wells covered by the permit are within the same well field, are of similar construction, and are of the same class.

(5) Professional Engineer of Record.

(a) All applications for construction permits shall be certified by a professional engineer registered in the State of Florida, except as provided in Rules [1]17-4.05(4)(a)-(e), FAC.

(b) The application, plans, and specifications, certification of construction completion reports, operation and maintenance manual, and other related documents shall be certified by a professional engineer of record registered in the State of Florida and retained by the applicant for that purpose.

(6) Area of Review.

(a) For Class I wells, the area of review study for a site shall be completed before the exploratory well or test injection well construction permits are issued.

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(b) The minimum area of review for a Class III proposed mining site shall initially include the entire proposed mining area plus a surrounding perimeter zone of one mile on all sides. The initial area of review study must be completed prior to construction, however, individual permit conditions will establish the interval, based on either the rate of geographical expansion of mining activity or a fixed period of time, at which the area of review study shall be updated.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

17-28.32 Class I - Exploratory Well Construction and Testing Permit.

(1) An exploratory well (as defined in this rule) under the Underground Injection Control Program is drilled for the specific purpose of obtaining sufficient information to determine the feasibility of underground injection at the proposed site. As such, it will be permitted under this rule as part of the entire proposed underground injection facility, and is exempt from any permitting requirements in Chapter 17-21, F.A.C.

(2) A permit to construct an exploratory well shall be denied by the permitting authority if the construction of the well itself will be a source of pollution as defined in Section 403.031, F.S.

(3) The information provided with the application to construct and test an exploratory well shall include, but not be limited to:

(a) Conceptual plan of the injection project;

(b) Preliminary area of review study;

(c) Proposed other uses of the exploratory well;

(d) Drilling and testing plan for the exploratory well;

(e) Abandonment plan;

(f) Proposed emergency effluent disposal method in the event of a pump or well failure.

(g) If the applicant proposes to convert the exploratory well to an injection well, all information required by Rule 17-28.33(2), FAC, shall be submitted prior to obtaining Department approval.

(4) Upon completion of the exploratory well program the Department will consider the recommendation of the Technical Advisory Committee

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when making the final decision concerning feasibility of injection at that site.

(5) During the period authorized by the exploratory well permit, the Department may require periodic inspections at certain stages of construction in accordance with Section 403.091, F.S.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

[1] **REGfile-system Editor's Note:** Reference to 17-4.05(4)(a)-(e) should be to 17-4.05(3), FAC.

17-28.33 Class I - Test/Injection Well Construction and Testing Permit and Class III - Well Construction/Operation/Plugging and Abandonment Permit.

(1) General.

(a) The Department shall deny a construction permit if construction of the well itself may be a source of pollution as defined in Section 403.031, F.S.

(b) For Class I, issuance of a construction permit does not obligate the permitting authority to authorize operation of the well, unless the well qualifies for an operation permit.

(c) For a Class III well or well field, a single permit for construction, operation, plugging, and abandonment may be issued.

(2) Information Requirements. Information to be submitted with the construction permit application shall include, but not be limited to, the following:

(a) A map showing the location of the proposed injection wells or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map;

(b) A tabulation of data on all wells within the area of review which penetrate into the proposed injection zone, confining zone, or proposed monitoring zone. Such data shall include a description of

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each well's type, construction, date drilled, location, depth, record of plugging and/or completion, and any additional information the Department may require;

(c) Maps and cross sections indicating the general vertical and lateral limits within the area of review of all underground sources of drinking water, their position relative to the injection formation and the direction of water movement, where known, in each underground source of drinking water which may be affected by the proposed injection;

(d) Maps and cross sections detailing the hydrology and geologic structures of the local area;

(e) Generalized maps and cross sections illustrating the regional geologic setting;

(f) Proposed operating data;

1. Average and maximum daily rate and volume of the fluid to be injected;

2. Average and maximum injection pressure; and

3. Source and an analysis of the chemical, physical, radiological and biological characteristics of injection fluids, including any additives for Class III wells. For Class I wells injecting domestic effluent, a demonstration that the effluent quality meet the standards specified in Rules 17-6.060(1)(a)4.a. and 17-6.080(4), FAC. For all other Class I wells, a demonstration that the effluent quality meet the standards specified in Rule 17-6.300(1)(p), FAC.

(g) Proposed formation testing program to obtain an analysis of the chemical, physical and radiological characteristics of and other information on the injection zone;

(h) Proposed stimulation program;

(i) Proposed injection procedure;

(j) Engineering drawings of the surface and subsurface construction details of the system, including design features for surge control and water hammer protection.

(k) Contingency plans to cope with all shut-ins or well failures, or, for Class III wells, catastrophic collapse, to protect the quality of the waters of the State as defined in Chapter 17-3, F.A.C., including emergency discharge provisions;

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PART III: CLASS I AND III WELL PERMITTING

(l) Plans (including maps) and proposed monitoring data to be reported for meeting the monitoring requirements in Rule 17-28.25, FAC;

(m) For wells within the area of review which penetrate the injection zone but are not properly completed or plugged, the corrective action proposed to be taken under Rule 17-28.13(5), FAC;

(n) Construction procedures including a cementing and casing program, logging procedures, deviation checks, and a drilling, testing and coring program;

(o) A certificate that the applicant has ensured, through a performance bond or other appropriate means, the resources necessary to close, plug or abandon the well as required by Rule 17-28.27(9), FAC;

(p) For Class III wells, expected changes in pressure, native fluid displacement, direction of movement of injection fluid;

(q) For Class III wells, a proposed monitoring plan, which includes a plan for detecting migration of fluids into underground sources of drinking water, a plan to detect water quality violations in the monitoring wells, and the proposed monitoring data to be submitted.

(3) Testing.

(a) For Class I, the construction permit includes a period of temporary injection operation for the purposes of long term testing. Each well shall first be tested for integrity of construction, and shall be followed by a short term injection test of such duration to allow for the prediction of the operating pressure.

(b) During the period authorized by the Class I Test/Injection Well Construction Permit, the permitting authority may require periodic inspections at certain stages of construction in accordance with Section 403.091, F.S.

(c) For Class III, the construction permit includes a period of temporary operation for the purpose of testing. Each well must first be tested for integrity of construction, prior to any injection testing.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

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PART III: CLASS I AND III WELL PERMITTING

17-28.34 Class I - Injection Well Operating Permit and Class III - Construction/Operation/Plugging and Abandonment Permit.

(1) General Requirements.

(a) When a Class I well is or will be operated as part of a municipal or industrial fluid treatment or disposal system which is or will be permitted by the Department, a separate operating permit need not be obtained for the injection well if it is permitted under a facility operating permit, except as provided in (e) below. If no other facility permit for a fluid treatment or disposal system exists or will be required, the owner shall apply for a separate permit for the well.

(b) During the period authorized by the operating permit, the Department may require periodic inspections in accordance with Section 403.091, F.S.

(c) A report shall be submitted with each application for a Class I well operation permit, which shall include, but not be limited to, the following information:

1. Results of the information obtained under the construction permit described in Rule 17-28.33(2), FAC;

2. Record drawings, based upon inspections by the engineer or persons under his direct supervision, with all deviations noted;

3. Certification of completion submitted by the engineer of record;

4. If requested by the Department, operation manual including emergency procedures;

5. Proposed monitoring program and data to be submitted;

6. Proof that the existence of the well and any associated monitoring wells has been recorded with the permanent warranty deed or other instrument of conveyance as a two page Proviso or addendum that contains certification of the locations of the wells (by metes and bounds) and a detailed sketch of the parcel that shows the location of the well. The location shall be measured by a Florida certified land surveyor, and shall contain the surveyor's signature, registration number, official seal, and the following statement: "I hereby certify that this survey was made under my responsible direction and supervision, is a correct representation of the land surveyed, that the permanent reference monuments and permanent control points have been set and that the survey data and monumentation complies with Chapter 177 of the Florida Statutes and Chapter 21HH-6 of the

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Florida Administrative Code."

7. Copies of mill certificates for casing used in the well(s) construction. The owner shall retain the original records.

(d) No Class I Injection Well Operating Permit shall be issued until the emergency disposal method is fully operational.

(e) For those Class I well sites that injected hazardous wastes before July 1983, a separate operating permit shall be obtained for each well at that site.

(2) Prior to granting approval for the operation of a Class I well or a Class III well or well field the Department shall consider the following information which, for Class I, was obtained during construction and operation under the construction permit:

(a) All available logging and testing program data and construction data on the well or well field;

(b) A satisfactory demonstration of mechanical integrity for all new wells pursuant to Section 17-28.13(6), F.A.C.;

(c) The actual operating data where feasible, or the anticipated maximum pressure and flow rate at which the permittee will operate, if approved by the Department;

(d) The results of the formation testing program;

(e) The actual injection procedure;

(f) For Class I, the compatibility of injected waste with fluids in the injection zone and minerals in both the injection zone and the confining zone;

(g) The status of corrective action on defective wells in the area of review;

(h) The recommendation of the Technical Advisory Committee concerning the operational feasibility of this well or well field.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

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17-28.35 Class I Well Plugging and Abandonment Permit and Class III Well Construction/Operation/Plugging and Abandonment Permit.

(1) A Class I or III well, or a test well or monitor well associated with a Class I or III well, shall be abandoned when it is no longer usable for its intended purpose or other purpose as approved by the Department, or when it poses a potential threat to the quality of the waters of the State.

(a) The Department or the applicant may initiate abandonment procedures.

(2) Prior to granting approval for the plugging and abandonment of a Class I or III well or a test or monitor well associated with a Class I or III well, the Department shall consider the following information:

(a) The justification for abandonment;

(b) A proposed plan for plugging and abandonment describing the preferred and alternate methods:

1. The type and number of plugs to be used;

2. The placement of each plug including the elevation of the top and bottom;

3. The type and grade and quantity of cement or any other approved plugging material to be used;

4. The method for placement of the plugs; and

(c) The procedure to be used to meet the requirement of Section 17-28.27, F.A.C.

(3) In the event of a well failure that requires abandonment, the applicant shall conduct an investigation to collect sufficient information to identify the most appropriate method to properly abandon the well.

(4) Upon completion of plugging and abandonment procedures, the engineer of record shall provide certification of completion in accordance with the plans and specifications.

(5) During the period authorized by the permit, the permitting authority may require periodic inspections at certain stages of plugging in accordance with Section 403.091, F.S.

(6) The permittee shall retain all records concerning the nature and composition of injected fluid until five (5) years after completion of any plugging and abandonment procedures specified under Section 17-28.27, F.A.C. The Department may require the owner or operator to deliver

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the records to the Department at the conclusion of the retention period.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, 403.702, 403.721, F.S.
History: New 4-1-82.

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PART III: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28.31(2)-(6)	Amendment	May 8, 1985: Specifying "appropriate fee" for application for permit; expanding to one mile width of surrounding perimeter zone as minimum area of review for Class III proposed mining site; revising rule reference titles.
17-28.32(3)	Amendment	May 8, 1985: Requiring inclusion in exploratory well application a proposed emergency effluent disposal method in event of pump or well failure; requiring information required by Rule 17-28.33(2) for proposal to convert exploratory well to injection well.
17-28.33(2)	Amendment	May 8, 1985: Requiring Class I wells injecting domestic effluent to demonstrate achievement of specified standards; requiring engineering drawings to include design features for surge control and water hammer protection; revising rule reference titles.
17-28.34(1)	Amendment	May 8, 1985: Strengthening general requirements for operating permits, including proof of survey; prohibiting issuance of Class I Well Operating Permit until emergency disposal method is fully operational; requiring separate operating permits for Class I well sites that injected hazardous wastes before July 1983.

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PART IV: CRITERIA AND STANDARDS FOR CLASS IV WELLS

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LISTING OF AMENDMENTS TO PART IV

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PART IV: CRITERIA AND STANDARDS FOR CLASS IV WELLS

17-28.41 General. For the purposes of this rule the definition of a Class IV well specifically includes any septic tank or cesspool used by generators of hazardous waste, or by owners or operators of hazardous waste management facilities, to dispose of fluids containing hazardous waste into or above an underground source of drinking water.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82.

17-28.42 General Prohibition of Class IV Wells. The Florida UIC Program shall prohibit:

(1) The construction of any Class IV well after the effective date of this rule;

(2) The operation of any Class IV well after the effective date of this rule.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.161, 403.702, 403.721, 403.727, F.S.
History: New 4-1-82.

17-28.43 Waste Analysis.

(1) The owner of a Class IV well shall submit to the Department a detailed chemical and physical analysis of a representative sample of the waste being injected on the effective date of this rule and the estimated or known quantity of the type of waste injected during the life of the well and;

(2) For wastes disposed of before the effective date of this rule and different than those specified in Section 28.43(1), the owner must identify the type and quantity to the best of his knowledge and in accordance with any records he has kept.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82.

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17-28.44 Ground Water Monitoring and Response. The owner of a facility which disposes of hazardous waste by underground injection into a Class IV well must monitor the ground water in accordance with the following:

(1) Applicability.

(a) Within one year after the effective date of this rule, the owner of an abandoned Class IV injection well must implement a ground water monitoring program capable of determining the facility's impact on the quality of ground water in all underground sources of drinking water underlying or adjacent to the facility, except as paragraph (c) of this Section provides otherwise.

(b) Except as paragraphs (c) and (d) of this Section provide otherwise, the owner shall install, operate, and maintain a ground water monitoring system which meets the requirements of Section 17-28.44(2) and must comply with Section 17-28.44(3)-(5). This ground water monitoring program shall be carried out for a period of time as determined by the Department, not to exceed 30 years.

(c) All or part of the ground water monitoring requirements of this Section may be waived if the owner can demonstrate that there is a low potential for migration of hazardous waste or hazardous waste constituents from the facility to underground sources of drinking water or to surface water. This demonstration shall be in writing. This demonstration shall be certified by a qualified geologist or geotechnical engineer, and shall establish the following:

1. The potential for migration of hazardous waste or hazardous waste constituents from the facility to an underground source of drinking water by an evaluation of:

a. A water balance of precipitation, evapotranspiration, runoff, and infiltration; and

b. Ground water characteristics (i.e., geologic materials, physical properties, and rate of ground water flow); and

2. The potential for hazardous waste or hazardous waste constituents which have entered an underground source of drinking water to migrate to a water supply well or surface water, by an evaluation of:

a. Ground water characteristics (i.e., geologic materials, physical properties, and rate of ground water flow); and

b. The proximity of the facility to water supply wells or surface water.

(d) If an owner determines that ground water monitoring of indica-

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tor parameters in accordance with Rule 17-28.44(2) and (3), FAC, would show statistically significant increases (or decreases in the case of pH) when evaluated under Rule 17-28.44(4)(b), FAC, he may, install, operate, and maintain an alternate ground water monitoring system. If the owner elects to use an alternate ground water monitoring system he shall:

1. Within one year after the effective date of this rule, submit to the Department a specific plan, certified by a qualified geologist or geotechnical engineer, which satisfies the requirements of Rule 17-28.44(4)(d)3., for an alternate ground water monitoring system;

2. Not later than one year after the effective date of this rule, initiate the determinations specified in Rule 17-28.44(4)(d)4.;

3. Prepare and submit a written report in accordance with Rule 17-28.44(4)(d)5.;

4. Continue to make the determinations specified in Rule 17-28.44(4)(d)4. on a quarterly basis until the Department decides the appropriate action to be taken, which may include:

a. Removing the contamination from the aquifer;

b. Installing ground water control devices;

c. Continued monitoring;

d. Cessation of monitoring; and

5. Comply with the recordkeeping and reporting requirements in Rule 17-28.44(5)(b), FAC.

(2) Ground Water Monitoring System.

(a) A ground water monitoring system shall be capable of yielding ground water samples for analysis and must consist of monitoring well(s) into each underground source of drinking water adjacent, above, or below the injection well. Their number, locations, and depths shall ensure that they immediately detect any statistically significant amounts of hazardous waste or hazardous waste constituents in any underground source of drinking water.

(b) The Department may require that background water quality data be collected from installed monitoring wells or that existing data for any underground sources of drinking water which may be affected by the injection of waste be submitted.

(c) All monitoring wells shall be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing shall be screened or perforated, and packed with gravel or sand where necessary, to enable sample collection at depths where appropriate aquifer flow zones exist. Alternate monitor well designs may be considered if it can be demonstrated that such configurations are more appropriate to site geology and hydrology. Such design shall be subject to Department approval. The annular space above the sampling depth must be sealed with a suitable material (e.g., cement grout or bentonite slurry) to prevent contamination of samples and the ground water.

(3) Sampling and Analysis.

(a) The owner shall obtain and analyze samples from the installed ground water monitoring system. The owner shall develop and follow a ground water sampling and analysis plan, and submit this plan to the Department. The plan shall include procedures and techniques for:

1. Sample collection;

2. Sample preservation and shipment;

3. Analytical procedures; and

4. Chain of custody control.

(b) The owner shall determine the concentration or value of parameters specified by the Department which may include but not be limited to:

1. Parameters characterizing the suitability of the ground water as a drinking water supply, as specified in Chapter 17-22, F.A.C.

2. Parameters establishing ground water quality:

a. Chloride

b. Iron

c. Manganese

d. Phenols

e. Sodium

f. Sulfate

3. Parameters used as indicators of ground water contamination:

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a. pH

b. Specific Conductance

c. Total Organic Carbon

d. Total Organic Halogen

(c) All monitoring wells shall be sampled and the samples analyzed on a quarterly basis unless otherwise authorized by the Department. Results of the analyses shall be submitted to the Department on a quarterly basis.

(d) Elevation of the ground water surface at each monitoring well must be determined each time a sample is obtained.

(4) Preparation, Evaluation and Response.

(a) The Department may after reviewing the ground water quality data submitted under Section 17-28.44(3)(c) require the owner to prepare and implement a ground water quality assessment program. The program would include a more comprehensive ground water monitoring plan than described in Sections 17-28.44(2) and (3), capable of determining:

1. Whether hazardous waste or hazardous waste constituents have entered an underground source of drinking water;

2. The rate and extent of migration of hazardous waste or hazardous waste constituents in an underground source of drinking water; and

3. The concentrations of hazardous waste or hazardous waste constituents in an underground source of drinking water.

(b) For each indicator parameter specified in Section 17-28.44(3)(b), the owner must calculate the arithmetic mean and variance, based on at least four replicate measurements on each sample, for each well monitored in accordance with Section 17-28.44(3)(c), and compared these results with its initial background arithmetic means.

(c) If the concentration or value of a parameter analyzed under Section 17-28.44(3)(b) exceeds maximum contaminant levels for drinking water in Chapter 17-22, F.A.C. or if the concentration or value is deemed significantly high (or low in the case of pH) by the Department, the owner shall obtain additional ground water samples, split the samples in two, and obtain analysis of all additional samples to determine whether the significant difference was a result of laboratory error.

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(d) 1. If the analyses performed under paragraph (c) of this Section confirm the significant increase (or pH decrease), the owner shall provide written notice to the Department within seven days of the date of such confirmation that the facility may be affecting ground water quality.

2. Within 15 days after the notification under paragraph (d)1. of this Section, the owner shall develop and submit to the Department a specific plan, based on the outline required under paragraph (a) of this Section and certified by a qualified geologist or geotechnical engineer, for a ground water quality assessment program at the facility.

3. The plan to be submitted under Section 17-28.44(1)(d)1. or paragraph (d)2. of this Section must specify:

a. The number, location, and depth of wells;

b. Sampling and analytical methods for those hazardous wastes or hazardous waste constituents in the facility;

c. Evaluation procedures, including any use of previously gathered ground water quality information; and

d. A schedule of implementation.

4. The owner shall implement the ground water quality assessment plan which satisfies the requirements of paragraph (d)3. of this Section, and, at a minimum, determine:

a. The rate and extent of migration of the hazardous waste or hazardous waste constituents in an underground source of drinking water; and

b. The concentrations of the hazardous waste or hazardous waste constituents in an underground source of drinking water.

5. The owner must make his first determination under paragraph (d)4. of this Section as soon as technically feasible, and within 15 days after the determination, submit to the Department a written report containing an assessment of the ground water quality.

6. If the owner determines, based on the results of the first determination under paragraph (d)4. of this Section, that no hazardous waste or hazardous waste constituents from the facility have entered an underground source of drinking water, then he may reinstate the indicator evaluation program described in Section 17-28.44(3) and paragraph (b) of this Section. If the owner rein-

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states the indicator evaluation program, he shall notify the Department in the report submitted under paragraph (d)5. of this Section.

7. If the owner determines, based on the first determination under paragraph (d)4. of this Section, that hazardous waste or hazardous waste constituents from the facility have entered an underground source of drinking water, then he:

a. Shall continue to make the determinations required under paragraph (d)4. of this Section on a quarterly basis until the Department notifies otherwise.

(5) Recordkeeping and Reporting.

(a) The owner shall:

1. Keep records of the analyses required in Section 17-28.44(3)(b) and (c), the associated ground water surface elevations required in Section 17-28.44(3)(d) and the evaluations required in Section 17-28.44(4)(b) throughout the post closure care period; and

2. Report the following ground water monitoring information to the Department.

a. Quarterly: concentrations or values of the parameters listed in Section 17-28.44(3)(b) for each ground water monitoring well, along with the required evaluations for these parameters under Section 17-28.44(4)(b).

(b) If the ground water is monitored to satisfy the requirements of Section 17-28.44(4)(d)4., the owner must:

1. Keep records of the analyses and evaluations specified in the plan, which satisfies the requirements of Section 17-28.44(4)(d)3., and throughout the post-closure care period; and

2. Submit to the Department quarterly reports containing the results of his ground water quality assessment program which include, but are not limited to, the calculated (or measured) rate of migration of hazardous waste or hazardous waste constituents in the ground water during the reporting period.

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 5-8-85.

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17-28.45 Closure and Post-Closure.

(1) Closure.

(a) The owner shall close his facility in a manner that:

1. Will prevent the migration of hazardous waste or hazardous waste constituents into or between underground sources of drinking water via the well structure; and

2. Will minimize the need for further maintenance to protect human health and the environment.

(b) Ninety days after the effective date of this rule the owner shall have a written closure plan. He shall keep this plan at the facility. This plan shall identify the steps necessary to completely close the facility. The closure plan shall:

1. Identify the techniques to be used to close the well in accordance with paragraph (c) of this Section;

2. Describe the steps which are necessary to decontaminate facility equipment during closure; and

3. Include a schedule for final closure which specifies the anticipated date when wastes will no longer be received, the anticipated date when final closure will be completed, and intervening milestone dates for tracking the progress of closure.

(c) The owner shall submit his closure plan to the Department at least 90 days before the date he expects to begin closure. The Department will modify, approve, or disapprove the plan within 90 days of receipt and after providing the owner or operator and the affected public the opportunity to submit written comments. If the owner plans to begin closure within 90 days after the effective date of this rule, he must submit the necessary plans on the effective date of this rule.

(d) Within 90 days after receiving the final volume of hazardous waste, the owner shall treat all hazardous wastes in storage or in treatment, or remove them from the site, or dispose of them on-site, in accordance with the approved closure plan.

(e) The owner shall complete closure activities in accordance within the approved closure plan and within nine (9) months after the effective date of this rule. The Department may approve a longer closure period under paragraph (c) of this Section if the owner can demonstrate that:

1. The required or planned closure activities will, of necessity,

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take him longer than nine (9) months to complete, and

2. That he has taken all steps to eliminate any significant threat to human health and the environment from the unclosed but inactive facility.

(f) At closure, the owner must:

1. Remove any hazardous waste remaining in the well; and

2. Close the well in a manner which satisfies paragraph (1) of this Section.

(g) When closure is completed, the owner shall submit to the Department certification both by the owner and by an independent registered professional engineer that the facility has been closed in accordance with the specifications in the approved closure plan.

(2) Post-Closure Care and Use of Property; Period of Care.

(a) The owner of a Class IV injection well must provide post-closure care. Post-closure care shall consist of at least:

1. Ground water monitoring and reporting in accordance with the requirements of Section 17-28.44; and

2. Maintenance activities of such frequency as to ensure the integrity of the containment structure and the function of the facility's monitoring equipment as specified in Section 17-28.44.

(b) The Department may require that access to the facility be prevented except by authorized personnel.

(c) Post-closure use of property on or in which hazardous waste remains after closure shall not disturb the integrity of any components of the containment system, or the function of the facility's monitoring systems, unless the owner can demonstrate to the Department, either in the post-closure plan or by petition, that the disturbance:

1. Is necessary to the proposed use of the property, and will not increase the potential hazard to human health or the environment; or

2. Is necessary to reduce a threat to human health or the environment.

(d) The owner of a disposal facility shall provide post-closure care in accordance with the approved post-closure plan for at least 30 years after the date of completing closure. However, the owner

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may petition the Department to allow some or all of the requirements for post-closure care to be discontinued or altered before the end of the 30-year period. The petition shall include evidence demonstrating the secure nature of the facility that makes continuing the specified post-closure requirement(s) unnecessary – e.g., no detected leaks and none likely to occur, characteristics of the waste, application of advanced technology, or alternative disposal treatment, or re-use techniques. Alternately, the Department may require the owner to continue one or more of the post-closure care and maintenance requirements contained in the facility's post-closure plan for a specified period of time. The Department may do this if it finds there has been noncompliance with any applicable standards or requirements, or that such continuation is necessary to protect human health or the environment. At the end of the specified period, the Department will determine whether to continue or terminate post-closure care and maintenance at the facility. Any person may petition the Department for an extension or reduction of the post-closure care period based on cause. Petitions will be considered by the Department when the post-closure plan is submitted and at five-year intervals after the completion of closure.

(3) Post-Closure Plan; Amendment of Plan.

(a) The owner of a disposal facility must submit his post-closure plan to the Department at least 90 days before the date he expects to begin closure. The Department shall modify or approve the plan within 90 days of receipt and after providing the owner and the affected public the opportunity to submit written comments. The plan may be modified to include security equipment maintenance under Section 17-28.45(2)(b). If an owner of a disposal facility plans to begin closure within 90 days after the effective date of these regulations, he shall submit the necessary plans on or before April 1, 1982. Any amendments to the plan under paragraph (b) of this Section which occur after approval of the plan must also be approved by the Department before they may be implemented.

(b) The owner may amend his post-closure plan at any time during the post-closure care period. The owner shall amend his plan any time changes in operating plans or facilities design affect his post-closure plan.

(4) Notice to Local Zoning Authority. Within 90 days after closure is completed, the owner of a disposal facility shall submit to the local zoning authority, to the Department, and to the United States Environmental Protection Agency, a survey plat indicating the location of the Class IV well with respect to permanently surveyed benchmarks. This plat shall be prepared and certified by a professional land surveyor. The plat filed with the local zoning authority shall contain a note, prominently displayed, which states the owner's obligation to

restrict disturbance of the site as specified in Section 17-28.45(2)(c). In addition, the owner shall submit to the local zoning authority, to the United States Environmental Protection Agency, and to the Department a record of the type, location, and quantity of hazardous wastes disposed of in the injection well. For wastes disposed of before this rule was promulgated, the owner shall identify the type, location and quantity of the wastes to the best of his knowledge and in accordance with any records he has kept.

(5) Notice in Deed to Property. The owner of the property on which a disposal facility is located shall publicly record the site in the county recording office in order to notify any potential purchaser of the property that the land has been used to manage hazardous waste, and its use is restricted under Section 17-28.45(2)(c).

Specific Authority: 403.061, 403.087, 403.101, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721, F.S.
History: New 4-1-82, Amended 8-30-82.

17-28.46 Financial Requirements.

(1) Ninety days after the effective date of this rule, the owner of a facility which disposes of hazardous waste by underground injection into or above an underground source of drinking water shall have a written estimate of the cost of closing the facility in accordance with the requirements in Section 17-28.45. The owner shall keep his estimate, and all subsequent estimates required in this Section, at the facility.

(2) The owner shall prepare a new closure cost estimate whenever a change in the closure plan affects the cost of closure.

(3) The owner shall maintain financial responsibility in the form of performance bonds or other equivalent form of financial assurance to close a facility which disposes of hazardous waste by underground injection. In lieu of individual performance bonds, owners may furnish a bond or other equivalent form of financial guarantee covering all facilities which dispose of hazardous waste by underground injection in this State.

(4) Ninety days after the effective date of this rule the owner of a facility which disposes of hazardous waste in a Class IV well shall have a written estimate of the annual cost of post-closure monitoring and maintenance in accordance with the applicable post-closure requirements in Section 17-28.45(2)-(5). This estimate, and all subsequent estimates, shall be kept at the facility.

(5) The cost estimate required in paragraph (4) of this Section shall be revised whenever a change in the post-closure care plan affects the

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cost of post-closure care (see Section 17-28.45(3)(b)). The latest post-closure cost estimate is calculated by multiplying the latest annual post-closure cost estimate by 30.

Specific Authority: 403.061, 403.087, 403.100, 403.704, 403.721, F.S.
Law Implemented: 403.021, 403.061, 403.062, 403.087, 403.101, 403.702, 403.721.
History: New 4-1-82.

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PART IV: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28.44(1)	Amendment	May 8, 1985: Correcting reference citations.

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PART V: CRITERIA AND STANDARDS FOR CLASS V WELLS

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LISTING OF AMENDMENTS TO PART V

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PART V: CRITERIA AND STANDARDS FOR CLASS V WELLS

17-28.51 General.

(1) Part V sets forth criteria and standards to regulate all injection wells not regulated in Parts I-IV.

(a) Generally, wells covered by this Part inject non-hazardous fluids into or above formations that contain underground sources of drinking water. It includes all wells listed in Rule 17-28.13(1)(e), FAC, but is not limited to those types of injection wells.

(b) It also includes wells not covered in Class IV that inject natural and manmade radioactive materials, provided these concentrations do not exceed current drinking water standards in Chapter 17-22, FAC.

(2) Classification of Class V Wells. Various types of Class V wells that exist or may exist in Florida are grouped together by expected quality of the injected fluid in order to facilitate the determination of permitting, operating, and monitoring requirements for these wells. The groups are:

(a) Group 1 - wells associated with thermal energy exchange processes, which include air conditioning return flow wells and cooling water return flow wells. Cooling water return flow wells may be part of a closed-loop system, with no hazardous additives, or part of an open-loop system that may use additives.

(b) Group 2 - recharge wells, saltwater intrusion barrier wells, connector wells, and subsidence control wells.

(c) Group 3 - wells which are part of domestic waste treatment systems, swimming pool drainage wells, injection wells used in experimental technologies, and wells used to inject spent brine into the same formation from which it was withdrawn after extraction of halogens or their salts.

(d) Group 4 - non-hazardous industrial and commercial disposal wells, which include laundry waste, dry wells, sand backfill wells, and nuclear disposal wells used to inject radioactive wastes, provided the concentrations of the waste do not exceed drinking water standards contained in Chapter 17-22, FAC, and injection wells used for in situ recovery of phosphate, uraniferous sandstone, clay, sand, and other minerals extracted by the borehole slurry mining method.

(e) Group 5 - lake level drainage and stormwater drainage wells.

(f) Group 6 - geothermal wells and 'other' wells.

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(3) The use of any Class V well for injection shall not present a hazard to any existing or future use of an underground source of drinking water.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82, Amended 8-30-82, 5-8-85.

17-28.52 Well Construction Standards for Class V Wells.

(1) The variety of Class V wells and their uses dictate a variety of construction designs consistent with those uses, and precludes specific construction standards for each type of Class V well outlined in this rule. However, a well must be designed and constructed for its intended use, in accordance with good engineering practices, and the design and construction must be approved by the Department.

(2) The Department may apply the design criteria for Class I wells (Part II of this rule), including surge and water hammer protection measures, and other factors to the construction of Class V wells.

(3) Class V wells shall be constructed so that their intended use does not violate the water quality standards of Chapter 17-3, FAC, at the point of discharge, except where specifically exempted in Rule 17-4.245(2)(b) and (c), FAC. Migration or mixing of fluid from aquifers of substantively different water quality (through the construction or use of a Class V well) shall be prevented by preserving the integrity of confining beds between these aquifers through cementing or some other method acceptable to the Department.

(4) All Class V wells shall be constructed by a State Licensed Water Well Contractor.

(5) A well completion report defining details of construction and describing various formations penetrated by the well shall be forwarded to the Department within two days after completion of the drilling operation.

(6) Samples of formations penetrated may be required. If required, samples shall be forwarded to the State Geologist, 903 West Tennessee Street, Tallahassee, Florida 32304, when drilling is completed.

(7) If casing is used within the well it shall, at a minimum, meet the requirements for water well construction set forth in Chapter 17-21, FAC.

(8) Class V wells shall be not dynamited except with written permission from the Department.

(9) A test well or boring shall be filled with cement within five days after completion of the testing for which it was drilled. Such test wells or borings shall not be used as drainage wells unless a permit has been obtained in accordance with this Chapter. Failure to obtain a permit prior to drilling of the

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well or boring shall bar future use except for testing purposes not connected with drainage in any manner.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82, Amended 5-8-85.

17-28.53 Operating Requirements for Class V Wells.

(1) All Class V wells shall be operated in such a manner that they do not present a hazard to an underground source of drinking water. Effluent quality shall meet the criteria established in Rules 17-6.060(1)(a)4.b. and 17-6.080(4), FAC.

(2) Pretreatment may be required for fluids injected through existing wells to insure that the injected fluid does not violate water quality standards.

(3) The Department shall impose operating requirements on Group 1 - cooling water return flow wells on an open-loop system, with additives; Group 3, except for swimming pool drainage wells; Group 4; and Group 6.

(4) The Department may impose operating requirements on Group 2 and 5.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82, Transferred from 17-4.27 and Amended 5-8-85.

17-28.54 Monitoring Requirements for Class V Wells.

(1) The need for monitoring shall be determined by the type of well, nature of the injected fluid, and water quality of the receiving aquifer. The Department may impose monitoring requirements for Groups 1, 2, 3, 5 and 6.

(2) The nature of the fluid being injected into or above an underground source of drinking water from Group 4 wells is such that the Department shall require monitoring for wells in this group.

(3) The Department shall determine the frequency of monitoring based on the location of the well, the nature of the injected fluid and, where applicable, the requirements of Chapter 17-6 and 17-19, F.A.C.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82.

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PART V: CRITERIA AND STANDARDS FOR CLASS V WELLS

17-28.55 Reporting Requirements for Class V Wells.

(1) Reporting requirements shall be determined by the type of well and nature of injected fluid. When necessary and where applicable, reporting shall be in accord with Chapters 17-6 and 17-19, F.A.C.

(2) Reporting shall be required for: Group 1 - cooling water return flow wells on an open-loop system, with additives; Group 3 - except for swimming pool drainage wells; and Group 4 and Group 6.

(3) The Department may require reporting for Groups 2 and 5.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82.

17-28.56 Plugging and Abandonment for Class V Wells.

(1) The Department may order a Class V well plugged and abandoned when it no longer performs its intended purpose, or when it is determined to be a hazard to the ground water resource.

(2) Prior to abandoning Class V wells the well shall be plugged with cement in a manner which will not allow movement of fluids between underground scurces of drinking water. The proposed plugging method and type of cement shall be approved by the Department. Placement of the cement shall be accomplished by any recognized method which is acceptable to the Department.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 403.021, 403.061, 403.062, 403.087, 403.101, F.S.
History: New 4-1-82.

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PART V: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
UPDATE: 5/85		
17-28.51(1)-(3)	Amendment	May 8, 1985: Correcting reference citations.
17-28.52(3)-(9)	Amendment	May 8, 1985: Strengthening well construction standards for Class V wells; adding new reporting and testing requirements.
17-28.53(1),(2)	Amendment	May 8, 1985: Requiring that effluent quality in Class V wells meet criteria established in sections of Chapter 17-6, FAC; allowing Department to include surge and water hammer protection measures in design criteria.

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PART VI: CLASS V WELL PERMITTING

17-28.61 General.

(1) Underground injection through a Class V well which begins operation after the effective date of this rule is prohibited except as authorized by permit. The construction or modification of any well required to have a permit under this Part is prohibited until the permit has been issued. In addition to the specific provisions of this Part, the general permitting provisions of Chapter 17-4, Part I, FAC, shall apply. Closed loop air conditioning return flow wells and swimming pool drainange wells are exempt from Rule 17-28.62, FAC, permitting requirements, but a general permit will be granted under Rules 17-4.73 and 17-4.74, FAC, respectively.

(2) No UIC authorization by permit or rule shall be allowed where a Class V well causes or allows movement of fluid containing any contaminant into underground sources of drinking water, and the presence of that contaminant may cause a violation of any primary drinking water regulation under Chapter 403, F.S. and Chapter 17-22, FAC or which may adversely affect the health of persons.

(3) If at any time the Department learns that an existing Class V well may cause a violation of primary drinking water regulations under Chapter 403, F.S. or Chapter 17-22, FAC, the Department shall:

(a) Require a permit for such Class V well;

(b) Order the injector to take such actions including where required, closure of the injection well as may be necessary to prevent the violation;

(c) Require monitoring to demonstrate that the water quality criteria in Rule 17-3.404, FAC, are not violated; or

(d) Take enforcement action.

(4) Whenever the Department learns that a Class V well may be otherwise adversely affecting the health of persons, the Department may prescribe such actions as may be necessary to prevent the adverse effect, including any action authorized under paragraph (3) of this Rule.

(5) Notwithstanding any other provision of this Section, the Department may take emergency action upon receipt of information that a contaminant which is present or is likely to enter a public water system may present an imminent and substantial endangerment to the health of persons.

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PART VI: CLASS V WELL PERMITTING

(6) The owner or operator of any new or existing Class V well shall, within one year of the effective date of an underground injection control program, notify the Department of the existence of any well meeting the definitions of Class V under his control, and submit the inventory information required in paragraph (7) below.

(7) As part of the inventory, the Department shall require at least the following information:

(a) Facility name and location, including a plot plan showing location of well(s);

(b) Name and address of legal contact;

(c) Ownership of facility;

(d) Nature and type of injection wells, including installed dimensions of wells and construction materials;

(e) Operating status of injection wells, including history of injection;

(f) Volume of injected fluid;

(g) Nature of injected fluid;

(h) Description of injection system, including monitoring well(s), if any.

(8) A group of similarly designed injection wells owned and operated by the same applicant serving the same purpose may be permitted as a system rather than as individual wells.

(9) Upon sale or legal transfer of a Class V well, the new owner shall notify the Department within thirty days. Until such time as notice of change in ownership is submitted, the owner reflected on the permit/clearance shall be responsible for the operation of the well and for damages resulting from improper operation of the wells.

(10) For Class V well fields or projects, the owner may apply for a single permit for the well field, provided all wells covered by the permit are within the same well field, are of similar construction, and are of the same group of Class V wells.

(11) When a Class V well is constructed and operated as part of a fluid treatment or disposal system which is permitted by the Department, a separate permit need not be obtained for the injection well. If no other facility permit for a fluid disposal or treatment system exists or will be required, the owner shall apply for a separate permit for the well. If an owner of a Class V well gives notice pursuant to Rule

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17-4.248(5), FAC, a separate permit need not be obtained for the injection well.

(12) Appropriate fees as specified in Rule 17-4.05(4), FAC, shall accompany application for any Class V well permit.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 373.313, 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, F.S.
History: New 4-1-82, Amended 5-8-85.

17-28.62 Construction/Clearance Permit for Class V Wells.

(1) All owners or operators of Class V wells shall obtain a two-part Construction/Clearance Permit, except as provided in Rule 17-28.61(1), FAC. The applicant shall submit to the Department at least the following information before receiving permission to construct:

(a) Facility name and location;

(b) Name, address, and signature of owner (or authorized representative) of facility;

(c) Name, address, license number, and signature of State Licensed Water Well Contractor;

(d) Well location and depth, and casing diameter and depth for all water supply wells on the applicant's property, and well location for all water supply wells of public record within a 1000 foot radius of the proposed well.

(e) Description and use of proposed injection system, including type and construction of injection wells, physical and chemical analyses, estimated quantity, pertinent bacteriological analyses of injected fluid, and any proposed pretreatment.

(f) Proposed drilling and testing plan for any exploratory borehole or exploratory well proposed for the purpose of determining feasibility of Class V well injection at that site.

(g) If the flow of surface or other waters is directed by ditches or other artificial methods to the well, a delineation of the area drained by these features shall be provided.

(2) The applicant may be requested to submit to the Department the following information before receiving permission to construct:

(a) Completed report of inspection by local programs or water management districts which have agreements with the Department.

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(b) Bacteriological examination of the injection fluid, on-site monitor wells, and the nearest down-gradient domestic or public water supply well within a 1000 foot radius that are drilled to the same formation(s) as the proposed Class V well. The bacteriological survey shall be conducted as follows:

1. Samples shall be collected from each well for the first three days of each week for four weeks.

2. Duplicate samples shall be collected in each case after the well has been pumped at least twenty minutes. Whenever a drainage well installation is approved following preliminary bacteriological survey of neighboring water supply wells, an identical survey of the same well shall be conducted following active use of the drainage well.

(c) If a drainage well or drainage structure will present a possible pollution hazard to an underground source of drinking water, additional data may be required.

(3) Upon completion of the well construction, the driller shall certify with the Department that the well has been completed in accordance with the approved construction plan, and submit any other additional information required by the construction permit before the well can be put into service.

(4) The Department may issue an authorization to use, which is non-renewable and non-expiring. The authorization may contain operating and reporting requirements.

(5) Initial and/or periodic testing of the well may be required for all Class V wells.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.308, 373.313, 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, F.S.
History: New 4-1-82, Amended 8-30-82, Transferred from 17-4.27 and Amended 5-8-85.

17-28.63 Operating Permit for Class V Wells.

(1) In addition to a Construction/Clearance Permit, the owner or operator of these wells:

(a) Shall obtain an operating permit for cooling water return flow wells on an open-looped system, with additives; Group 3 wells except for swimming pool drainage wells; and Group 4 wells;

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(b) May be required to obtain an operating permit for sand backfill and Group 6 wells;

(c) Are not required to obtain operating permits for wells in Groups 1, 2, and 5 with the exception of cooling water return flow wells on an open-looped system.

(2) Operating permits shall be issued for a period not to exceed five years.

(3) At least 60 days prior to expiration of an operating permit, the owner or operator shall apply for renewal of his permit.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.309, 373.313, 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, F.S.
History: New 4-1-82, Amended 5-8-85.

17-28.64 Plugging and Abandonment Permit for Class V Wells.

(1) The owner or operator of any Class V well shall apply for a Plugging and Abandonment Permit when the well is no longer used or usable for its intended purpose or other purpose as approved by the Department. The application shall include the proposed plugging plan and justification for abandonment. Plugging shall be performed by a State Licensed Water Well Contractor.

(2) Upon completion of plugging and abandonment procedures, the engineer of record shall provide certification of completion in accordance with the plans and specifications.

(3) The owner or operator of any Class V well may be required to provide evidence, such as a sealed copy of certification from the county clerk, that a surveyor's plot of the location of the abandoned well has been recorded in the county courthouse property records.

Specific Authority: 373.309, 403.061, 403.087, 403.101, F.S.
Law Implemented: 373.309, 373.313, 403.021, 403.061, 403.062, 403.087, 403.088, 403.101, 403.161, F.S.
History: New 4-1-82, Amended 5-8-85.

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PART VI: LISTING OF AMENDMENTS

SECTION	CHANGE	EFFECTIVE DATE: DESCRIPTION OF CHANGE
17-28.61(1)-(4), (11),(12)	Amendment	May 8, 1985: Exempting closed-loop air conditioning return flow wells and swimming pool drainage wells from permitting requirements of 17-28.62, FAC (but granting general permit under 17-4, FAC); requiring in certain cases of violations by Class V wells a monitoring to demonstrate that certain water quality criteria are not violated; requiring fees for Class V well permits; revising certain rule reference titles.
17-28.62(1)-(5)	Amendment	May 8, 1985: Expanding required information for Class V well construction permits; allowing Department to request further information as needed.
17-28.63(1),(3)	Amendment	May 8, 1985: Changing term "permittee" of any Class V well to "owner or operator."
17-28.64(1),(3)	Amendment	May 8, 1985: Changing term "permittee" of any Class V well to "owner or operator"; adding that plugging shall be performed by a State Licensed Water Well Contractor.

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STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

CONSTRUCTION/CLEARANCE PERMIT APPLICATION FOR CLASS V WELL

(Depending on the nature of proposed injection well system, the Department may require the use of Form 17-1.209(9) in lieu of this form.)

In compliance with Chapter 403, Florida Statutes, the undersigned water well contractor applies for a permit and approval from the Department of Environmental Regulation for the installation of a Class V well on the following property owned by:

Corporation or Owner's Name

Facility Name
SIC Code

Facility Address City County Zip
Latitude/Longitude

Type of Discharge

It is understood that the Department reserves the right, under the Statutes, to revoke the permit should this well at any time contaminate or otherwise affect other waters in the vicinity, or for other cause.

OWNER OR AUTHORIZED REPRESENTATIVE*(circle one)

Name and Official Title (Printed or typed)

Street City State Zip
Telephone Number

Owner or Authorized Representative's* Signature
Date

*Attach letter of authorization.

WATER WELL CONTRACTOR:

Water Well Contractor's Name, Title and State License Number (Printed or typed)

Street City State Zip
Telephone Number

Water Well Contractor's Signature
Date

DER FORM 17-1.209(1)
Effective November 30, 1982

PROJECT DESCRIPTION

Type of Class V Injection Well: (Indicate number of each well type)

Group 1

A/C Return Flow Wells ____

Cooling Water Return Flow Wells, Closed-looped System ____

Group 2

Connector Wells ____

Recharge Wells ____

Dry Wells ____

Group 3

Wells Receiving Domestic Waste ____

Swimming Pool Drainage Wells ____

Group 4

Laundry Waste Wells ____

Other Non-hazardous Industrial or Commercial Disposal Wells (explain) ____

Group 5

Lake Level Drainage Wells

Stormwater Drainage Wells ____

Group 6

OTHER (explain) ____

____

Description and Use of Proposed Injection System:

(If the proposed well is to receive stormwater, a drainage plan of the area draining to the well should be included. The drainage plan should illustrate any septic tanks, landfills, farm operations or other installations and/or landscape features which could contribute to stormwater contamination.)

____

____

____

Nature and Volume of Injection Fluid:

(The Department may require an analysis, including bacteriological analysis, in accordance with Section 17-4.27(2)(c).)

____

____

____

Proposed Pretreatment: ____

____

Include a plot plan showing location of well(s).

Well Design and Construction Details:

(Complete for each well, and, for multi-casing configurations or unusual construction provisions an elevation drawing of the proposed well should be included.)

Proposed Total Depth: ____________ feet

Depth of Casing(s): __________________________ feet

Diameter of Well: ____________ inches

Type of Casing:

Cement: Type ____________________

____PVC ____Steel ____Other ____None

Depth ____________________

Thickness ____________________

Water Supply Wells:

When required by Florida Administrative Code Rule 17-4.27 attach a map section showing the locations of all water supply wells within a one (1) mile radius of the proposed well. The well depths, and casing depths should be included. When required by Rule 17-4.27(2)(g), results of bacteriological examinations of water from all water supply wells within one (1) mile and drilled to approximate depth of proposed well should be attached.

Area of Review: (may be required at Department's discretion)

Include the proposed radius of the area of review with justification for that radius. Provide a map showing the location of the proposed injection well or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map.

____

____

____

INSPECTION REPORT ON CLASS V WELL
(for agency use only)

THE FOLLOWING REPORT OF INSPECTION TO BE COMPLETED BY: ______________________________

____

____

Local Program/Water Management District

This is to certify that I have this _____day of _______________ 19____, investigated this application for a permit, and recommend (a) approval (b) disapproval for the following reasons:

____

____

____

____________________ Date

____ Signature

____ Name and Title (Please Type)

DER FORM 17-1.209(1)
Effective November 30, 1982

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

CERTIFICATION OF CLASS V WELL CONSTRUCTION COMPLETION

INSTRUCTIONS: Submit this certification to the department along with a signed copy of the Well Completion Report, DER Form 17-1.213(2).

DER Construction Permit No. ______________, issued on ______________ (Date). County __________

Owner's Name ____

Owner's Address ____
(Street) (City) (State) (Zip Code)

Well Contractor's Name ____
(Title) (State License No.)

Well Contractor's Address _____________________________________
(Street) (City) (State) (Zip Code)

Well Location ____

Deviations from the application and plans approved by the department: __________
____
____

Actual Dimensions:

Diameter ________ inches
Well depth ________ feet
Casing depth ________ feet

This is to certify that, with the exception of the deviations noted above, the construction of this well has been completed in accordance with the plans authorized by Construction Permit No. ______________, dated ______________.

Date: ______________ ______________________________
(Contractor's Signature)

DER Form 17-1.209(2)
Effective November 30, 1982.

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

Owner's Name:
Owner's Address:

This will acknowledge receipt of the required Certification of Class V Well Construction Completion and the Well Completion Report for a well constructed under DER Permit

No. ________________________, dated ________________________. by ________________________

and located at ____

____

Based upon a review of this information the placing of this well into service is hereby authorized. Pursuant to Chapter 403, Florida Statutes, this authorization may be rescinded if the disposal well should, at any time, contaminate or otherwise adversely affect other water in the vicinity, or it may be recinded for any other condition contained in Florida Administrative Code Rule 17-4.10 or 17-28.61(3) through (5). Pursuant to Florida Administrative Code Rule 17-28.62(3), this authorization to use is non-renewable and non-expiring.

Upon sale or legal transfer of this well, the new owner must notify the department within thirty (30) days. Until such time as the notice of change in ownership is submitted, you will be responsible for the operation of this well and for damages resulting from improper operation of the well in accordance with Florida Administrative Code Rule 17-28.61(9). The use of this well is subject to the following specific conditions:

Sincerely,

District Manager

DER Form 17-1.209(3)
Effective November 30, 1982

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

APPLICATION FOR CLASS V WELL PLUGGING AND ABANDONMENT PERMIT

Owner's Name

Owner's Address City County Zip

Authorized Representative* (may be same as owner) Telephone Number
*Attach letter of authorization

Authorized Representative's Address City County Zip

Name of Facility

Address of Facility City County Zip

___°___'___" ___°___'___" ___1/4___1/4___1/4 of ________
Latitude/Longitude of well Section, Township, Range

WATER WELL CONTRACTOR:

Water Well Contractor's Name, Title and State License Number (Printed or typed)

Street City State Zip

Existing Permits: (yes____no____) Permit Number(s)________

Permit is for well only [ ] Permit is for facility associated with well [ ]

Description of Proposed Plugging Plan: (include method of plugging, placement of plugs, type and quantity of cement, etc. Attach additional sheets as necessary.)

Reason for Abandonment:

____

____

____

____

Well Design and Construction Details (complete for each well):

Depth of open hole ____________________ Diameter of well ______________inches

Depth of casing(s) ____________________

Type of casing: ____PVC ____Steel ____Other ____None

Cement: Type _______________ Depth _______________ Thickness ____________

Operating Status of Wells:

Active ☐ Years in Operation _______

Currently Not in Use ☐ Years in Operation _______ Date of Last Use __________

Description of Injected Fluid:

Nature of Fluid____

____

Volume of Fluid _______________gpd (average) _______________gpd (design or max.)

The Department may require, where necessary, that a recent geophysical log be included.

____

Owner or Authorized Representative's Signature

____

Date Telephone Number

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

WIN TOWERS OFFICE BUILDING
.600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

CERTIFICATION OF PLUGGING COMPLETION
CLASS I, III OR V WELL

Pursuant to Florida Administrative Code Rules 17-28.26(4)(a)2. and 17-28.64(3), the permittee must provide evidence (such as a sealed copy of certification from the county clerk) that a surveyor's plot of the location of the abandoned well has been recorded in the county courthouse property records. Submit this information to the Department of Environmental Regulation, 2600 Blair Stone Road, Twin Towers Building, Tallahassee, Florida 32301.

A Class I, III, or V well was plugged in accordance with Permit # ____________________

issued ____________________ (date), and located at ______________________________

ACTUAL DIMENSIONS:

Diameter ____________ inches
Well Depth ____________ feet
Casing Depth ____________ feet

DATE PLUGGED ____________________

PLUGGING METHOD ____________________

____
Date

____
Signature

____
Engineer of Record or Water Well Contractor
(Please print or type name)

____
Address

____

____
Phone Number

____
Date

____
Signature

____
Owner or Authorized Representative*
(Please print or type name)

*Attach letter of authorization

____
Address

____

____
Phone Number

ER FORM 17-1.209(7)
Effective November 30, 1982

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

NOTIFICATION TO FDER OF CLASS V WELL OWNERSHIP

PART I General:

Owner's Name (Print or Type) ______ Owner's Signature ______

Owner's Address ______ City ______ County ______ Zip ______

Legal Contact (may be same as owner) ______ Telephone Number ______

Legal Contact's Address ______ City ______ County ______ Zip ______

Name of Facility ______

Address of Facility ______ City ______ County ______ Zip ______

Latitude/Longitude of Class V Well(s) ______

PART II Type of Injection Well:

(Indicate number of each type of well; for wells with multiple uses, describe each use.)

______ A/C Return Flow Wells

______ Cooling Water Return Flow Wells, Open-looped System

______ Cooling Water Return Flow Wells, Closed-looped System

______ Recharge Wells

______ Connector Wells

______ Subsidence Control Wells

______ Lake Level Drainage Wells

______ Experimental Technology Wells

______ Salt-water Intrusion Barrier Wells

______ Swimming Pool Drainage Wells

______ Wells Receiving Domestic Waste

______ Dry Wells

______ Laundry Waste Wells

______ Sand Backfill Wells

______ Geothermal Wells

______ Radioactive Waste Disposal Wells

______ Stormwater Drainage Wells

______ Borehole Slurry Mining Wells

______ Other (explain; use additional sheets as necessary)

DER Form 17-1.209(8)
Effective November 30, 1982

PART III Well Design and Construction Details

(Complete for each well. Attach separate sheet, if necessary, for multiple wells.):

Depth of open hole ______________feet Diameter of well ______________inches

Depth of casing(s) ______________feet

Type of casing: ____PVC ____Steel ____Other ____none

Cement: Type ________________

Depth ________________

Thickness ________________

Name of Water Well Contactor/Driller:____

Address:____

PART IV Operating Status of Well(s)

(Attach separate sheet, if necessary, for multiple wells):

Active [ ] Years in Operation ________

Currently not in use [ ] Years in Operation ________ Date of last use ______________

Plugged [ ] Years in Operation ________ Date of last use ______________

Date of Plugging ____________________ Method of Plugging ______________

Plugging Contractor ____

Address ____

PART V Description of Injection Fluid:

Nature of Fluid____

____

Volume of Fluid ____________________________gpd (average)

____________________________gpd (design or maximum)

PART VI Injection System:

Describe the injection system, including the number, depth and location of any monitoring wells.

____

____

____

PART VII

Distance and direction to nearest water supply well within a one (1) mile radius of the injection well: (e.g., 500 yards N.E. of injection well)

PART VIII Existing Permits:

[ ] None

DER Permit Number(s): ____________________

[ ] Permit is for well only.

[ ] Permit is for facility associated with well.

Water Management District Permit Number(s): ____________________

[ ] Permit is for well only.

[ ] Permit is for facility associated with well.

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

APPLICATION TO CONSTRUCT/OPERATE/ABANDON CLASS I, III, OR V INJECTION WELL SYSTEMS

PART I. Directions

A. All applicable items must be completed in full in order to avoid delay in processing this application. Where attached sheets or other technical documentation are utilized in lieu of the blank space provided, indicate appropriate cross-reference in the space and provide copies to the department in accordance with (C) below. Where certain items do not appear applicable to the project, indicate N/A in the appropriate spaces. When this form is used in conjunction with DER Form 17-1.205(1), duplicative information requests need to be completed only once.

B. All information is to be typed or printed in ink.

C. Four (4) copies of this application and four (4) copies of supporting information such as plans, reports, drawings and other documents shall be submitted to the appropriate District/Subdistrict office. An engineering report is also required to be submitted to support this application pursuant to the applicable sections of Florida Administrative Code Rule 17-28. The attached lists* shall be used to determine completeness of supporting data submitted or previously received. A check for the application fee in accordance with Florida Administrative Code Rule 17-4.05 made payable to the Department shall accompany the application.

D. For projects involving construction, this application is to be accompanied by four (4) sets of engineering drawings, specifications and design data as prepared by a Professional Engineer registered in Florida, where required by Chapter 471, Florida Statutes.

E. Attach 8 1/2" x 11" USGS site location map indicating township, range and section and latitude/longitude for the project.

PART II. General Information

A. Applicant: Name______________________________ Title________________

Address____

City______________________________________ Zip______________

Telephone Number______________________________

B. Project Status: [ ] New [ ] Existing

[ ] Modification (specify)____

*"Engineering and Hydrogeologic Data Required for Support of Application to Construct, Operate and Abandon Class I, III, or V Injection Wells"

DER FORM 17-1.209(9)
Effective November 30, 1982

C. Well Type:

( ) Exploratory Well ( ) Test/Injection Well

D. Type of Permit Application:

( ) Class I Exploratory Well Construction and Testing Permit

( ) Class I Test/Injection Well Construction and Testing Permit

( ) Class I Well Operating Permit

( ) Class I Well Plugging and Abandonment Permit

( ) Class III Well Construction/Operation/Plugging and Abandonment Permit

( ) Class V well Construction Permit

( ) Class V Well Operating Permit

( ) Class V Well Plugging and Abandonment Permit

E. Facility Identification:

Name:____

Facility Location: Street:____________________________

City:______________________County:______________

SIC Code:____________________________________

F. Proposed facility located on Indian Lands: Yes_____ No_____

G. Well Identification:

Well No._____ of _________Wells
(total #)

Purpose (Proposed Use):______________________________

Well Location: Latitude:____________________ Longitude____________________

(attach separate sheet, if necessary, for multiple wells.)

Subpart B. General Projection Description:

(1) Describe the nature, extent and schedule of the injection well project. Refer to existing and/or future pollution control facilities, expected improvement in performance of the facilities and state whether the project will result in full compliance with the requirements of Chapter 403, Florida Statutes, and all rules and regulations of the Department. Attach additional sheet(s) if necessary or cross-reference the engineering report.

____

____

____

PART III Statement by Applicant and Engineer

A. Applicant

I, the owner/authorized representative* of ________________________________, certify under penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. I understand that this certification also applies to all subsequent reports submitted pursuant to this permit. Where construction is involved, I agree to retain the design engineer, or other professional engineer registered in Florida, to provide inspection of construction in accordance with Florida Administrative Code Rule 17-28.34(1)(c).

________________________________ ________________
Signed Date

________________________________ ________________
Name and Title (Please Type) Telephone Number

*Attach a Letter of Authorization.

B. Professional Engineer Registered in Florida

This is to certify that the engineering features of this injection well have been designed/examined by me and found to be in conformity with modern engineering principles applicable to the disposal of pollutants characterized in the permit application. There is reasonable assurance, in my professional judgement, that the well, when properly maintained and operated, will discharge the effluent in compliance with all applicable statutes of the State of Florida and the rules and regulations of the Department. It is also agreed that the undersigned will furnish the applicant a set of instructions for proper maintenance and operation of the well.

Signed: ________________________________

____
Name (Please Type)

____
Company Name (Please Type)

(Please Affix Seal)

____
Mailing Address (Please Type)

FLORIDA REGISTRATION NUMBER______________ Date:______________Phone No.______________

ENGINEERING AND HYDROLOGIC DATA
REQUIRED FOR SUPPORT OF APPLICATION
TO CONSTRUCT, OPERATE, AND ABANDON
CLASS I, III, OR V INJECTION WELL SYSTEMS

The following information shall be provided for each type of permit application.

(A) CLASS I EXPLORATORY WELL CONSTRUCTION AND TESTING PERMIT

(1) Conceptual plan of the injection project. Include number of injection wells, proposed injection zone, nature and volume of injection fluid, and proposed monitoring program.

(2) Preliminary Area of Review Study. Include the proposed radius of the area of review with justification for that radius. Provide a map showing the location of the proposed injection well or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surfacebodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map.

(3) Proposed other uses of the exploratory well.

(4) Drilling and testing plan for the exploratory well. The drilling plan mu specify the proposed drilling program, sampling, coring, and testing procedures.

(5) Abandonment Plan.

(B) CLASS I TEST/INJECTION WELL CONSTRUCTION AND TESTING PERMIT

(1) A map showing the location of the proposed injection wells or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map.

(2) A tabulation of data on all wells within the area of review which penetrate into the proposed injection zone, confining zone, or proposed monitoring zone. Such data shall include a description of each well's type, construction, data drilled, location, depth, record of plugging and/or completion, and any additional information the Department may require.

(3) Maps and cross sections indicating the general vertical and lateral limits within the area of review of all underground sources of drinking water, their position relative to the injection formation and the direction of water movement, where known, in each underground source of drinking water which may be affected by the proposed injection.

(4) Maps and cross sections detailing the hydrology and geologic structures of the local area.

(5) Generalized maps and cross sections illustrating the regional geologic setting.

(6) Proposed operating data.

- a. Average and maximum daily rate and volume of the fluid to be injected;
- b. Average and maximum injection pressure; and,
- c. Source and an anlysis of the chemical, physical, radiological and biological characteristics of injection fluids.

(7) Proposed formation testing program to obtain an analysis of the chemical, physical and radiological characteristics of and other information on the injection zone.

(8) Proposed stimulation program.

(9) Proposed injection procedure.

(10) Engineering drawings of the surface and subsurface construction details of the system.

(11) Contingency plans to cope with all shut-ins or well failures, so as to protect the quality of the waters of the State as defined in Florida Administrative Code Rule 17-3, including alternate or emergency discharge provisions.

(12) Plans (including maps) and proposed monitoring data to be reported for meeting the monitoring requirements in Florida Administrative Code Rule 17-28.25.

(13) For wells within the area of review which penetrate the injection zone but are not properly completed or plugged, the corrective action proposed to be taken under Florida Administrative Code Rule 17-28.13(5).

(14) Construction procedures including a cementing and casing program, logging procedures, deviation checks, proposed methods for isolating drilling fluids from surficial aquifers, proposed blowout protection (if necessary), and a drilling, testing and coring program.

(15) A certification that the applicant has ensured, through a performance bond or other appropriate means, the resources necessary to close, plug or abandon the well as required by Florida Administrative Code Rule 17-28.27(9).

(C) CLASS I INJECTION WELL OPERATING PERMIT

(1) A report shall be submitted with each application for a Class I well operation permit, which shall include, but not be limited to, the following information:

a. Results of the information obtained under the construction permit described in (B)-CLASS I TEST/INJECTION WELL CONSTRUCTION AND TESTING PERMIT, including:

1. All available logging and testing program data and construction data on the well or well field;

2. A satisfactory demonstration of mechanical integrity for all new wells pursuant to Florida Administrative Code Rule 17-28.13(6)(b);

3. The actual operating data, including injection pressures versus pumping rates where feasible, or the anticipated maximum pressure and flow rate at which the permittee will operate, if approved by the Department;

4. The actual injection procedure;

5. The compatibility of injected waste with fluids in the injection zone and minerals in both the injection zone and the confining zone; and,

6. The status of corrective action on defective wells in the area of review.

b. Record drawings, based upon inspections by the engineer or persons under his direct supervision, with all deviations noted;

c. Certification of completion submitted by the engineer of record;

d. If requested by the Department, operation manual including emergency procedures;

e. Proposed monitoring program and data to be submitted;

f. Proof that the existence of the well has been recorded on the surveyor's plan at the county courthouse.

g. Proposed plugging and abandonment plan pursuant to Florida Administrative Code Rule 17-28.27(2).

(D) CLASS I WELL PLUGGING AND ABANDONMENT PERMIT

(1) The reasons for abandonment.

(2) A proposed plan for plugging and abandonment describing the preferred and alternate methods, and justification for use.

a. The type and number of plugs to be used;

b. The placement of each plug including the elevation of the top and bottom;

c. The type and grade and quantity of cement or any other approved plugging material to be used;

d. The method for placement of the plugs.

(3) The procedure to be used to meet the requirements of Rule 17-28.27.

(E) CLASS III WELL CONSTRUCTION/OPERATION/PLUGGING AND ABANDONMENT PERMIT

Construction Phase

(1) A map showing the location of the proposed injection wells or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map.

(2) A tabulation of data on all wells within the area of review which penetrate into the proposed injection zone, confining zone, or proposed monitoring zone. Such data shall include a description of each well's type, construction, date drilled, location, depth, record of plugging and/or completion, and any additional information the Department may required.

(3) Maps and cross sections indicating the general vertical and lateral limits within the area of review of all underground sources of drinking water, their position relative to the injection formation and the direction of water movement, where known, in each underground source of drinking water which may be affected by the proposed injection.

(4) Maps and cross sections detailing the hydrology and geologic structures of the local area.

(5) Generalized maps and cross sections illustrating the regional geologic setting.

(6) Proposed operating data:

a. Average and maximum daily rate and volume of the fluid to be injected;

b. Average and maximum injection pressure; and,

c. Source and an analysis of the chemical, physical, radiological and biological characteristics of injection fluids, including any additives.

(7) Proposed formation testing program to obtain an analysis of the chemical, physical and radiological characteristics of and other information on the injection zone.

(8) Proposed stimulation program.

(9) Proposed injection procedure.

(10) Engineering drawings of the surface and subsurface construction details of the system.

(11) Contingency plans to cope with all shut-ins or well failures or catastrophic collapse, so as to protect the quality of the waters of the state as defined in Florida Administrative Code Rule 17-3, including alternate or emergency discharge provisions.

(12) Plans (including maps) and proposed monitoring data to be reported for meeting the monitoring requirements in Florida Administrative Code Rule 17-28.25.

(13) For wells within the area of review which penetrate the injection zone but are not properly completed or plugged, the corrective action proposed to be taken under Florida Administrative Code Rule 17-28.13(5).

(14) Construction procedures including a cementing and casing program, logging procedures, deviation checks, proposed methods for isolating drilling fluids form surficial aquifers, and a drilling, testing and coring program.

(15) A certificate that the applicant has ensured, through a performance bond or other appropriate means, the resources necessary to close, plug or abandon the well as required by Florida Administrative Code Rule 17-28.27(9).

(16) Expected changes in pressure, native fluid displacement, direction of movement of injection fluid.

(17) A proposed monitoring plan, which includes a plan for detecting migration of fluids into underground sources of drinking water, a plan to detect water quality violation in the monitoring wells, and the proposed monitoring data to be submitted.

Operation Phase

(1) The following information shall be provided to the Department prior to granting approval for the operation of the well or well field:

a. All available logging and testing program data and construction data on the well or well field;

b. A satisfactory demonstration of mechanical integrity for all new wells pursuant to Florida Administrative Code Rule 17-28.13(6)(b);

c. The actual operating data, including injection pressure versus pumping rate where feasible, or the anticipated maximum pressure and flow rate at which the permittee will operate, if approved by the Department;

d. The results of the formation testing program;

e. The actual injection procedure;

f. The status of corrective action on defective wells in the area of review.

Plugging and Abandonment Phase

(1) The justification for abandonment.

(2) A proposed plan for plugging and abandonment describing the preferred and alternate methods.

a. The type and number of plugs to be used;

b. The placement of each plug including the elevation of the top and bottom;

c. The type and grade and quantity of cement or any other approved plugging material to be used;

d. The method for placement of the plugs.

(3) The procedure to be used to meet the requirements of Florida Administrative Code Rule 17-28.27.

(F) CLASS V WELL CONSTRUCTION PERMIT. (This form should be used for Class V wells instead of Form 17-1.209(1) when there is a need for a Technial Advisory Committee and an engineering report.)

(1) Type and number of proposed Class V Wells:

Wells Receiving Domestic Waste	_____	Salt-water Intrusion Barrier Wells	_____
Cooling Water Return Flow Wells, Open-looped System	_____	Subsidence Control Wells	_____
		Sand Backfill Wells	_____

Experimental Technology Wells ____

Radioactive Waste Disposal Wells* ____

Other non-hazardous Industrial or Commercial Disposal Wells (explain) ________________

Wells used to inject spent brine after halogen recovery ____

Borehole Slurry Mining Wells ____

Other (explain) ________________

*Provided the concentrations of the waste do not exceed drinking water standards contained in Chapter 17-22, F.A.C.

(2) Project Description:

a. Description and use of proposed injection system;

b. Nature and volume of injected fluid (The Department may require an analysis (including bacteriological analysis) in accordance with Florida Administrative Code Rule 17-4.27(2)(c));

c. Proposed pretreatment.

(3) Water well contractor's name, title, state license number, address, phone number and signature.

(4) Well Design and Construction Details. (For multi-casing configurations or unusual construction provisions, an elevation drawing of the proposed well should be attached.)

a. Proposed total depth;

b. Proposed depth and type of casing(s);

c. Diameter of well;

d. Cement type, depth, thickness;

e. Injection pumps (if applicable): ____gpm @____psi

Controls: ________________

____

____

(5) Water Supply Wells - When required by Florida Administrative Code Rule 17-4.27, attach a map section showing the locations of all water supply wells within a one (1) mile radius of the proposed well. The well depths and casing depths should be included. When required by Rule 17-4.27(2)(g), results of bacteriological examinations of water from all water supply wells within one (1) mile and drilled to approximate depth of proposed well should be attached.

(6) Area of Review (may be required at Department's discretion).

Include the proposed radius of the area of review with justification for that radius. Provide a map showing the location of the proposed injection well or well field area for which a permit is sought and the applicable area of review. Within the area of review, the map must show the number or name, and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, public water systems, mines (surface and subsurface), quarries, water wells and other pertinent surface features including residences and roads. The map should also show faults, if known or suspected. Only information of public record and pertinent information known to the applicant is required to be included on this map.

(G) CLASS V WELL OPERATION PERMIT (Final report of the construction that includes the following information may be submitted with the application to operate.)

(1) Permit Number of Class V Construction Permit: ____________________

(2) Owner's Name: ____________________

(3) Type of Well: ____________________

(4) Construction and Testing Summary:

a. Actual Dimensions:

Diameter ______ inches; Well Depth ________ feet; Casing Depth ______ feet.

______ ________ ______

______ ________ ______

b. Results of Initial Testing.

(5) Proposed Operating Data:

a. Injection Rate (GPM);

b. Description of injected waste;

c. Injection pressure and pump controls.

(6) Proposed Monitoring Plan (If any):

a. Number of monitoring wells;

b. Depth(s);

c. Parameters;

d. Frequency of sampling;

e. Instrumentation (if applicable) Flow ____________________

Pressure ____________________

(H) CLASS V WELL PLUGGING AND ABANDONMENT PERMIT

(1) Permit number of Class V construction or operating permit.

(2) Type of well.

(3) Proposed plugging procedures, plans and specifications.

(4) Reasons for abandonment.

STATE OF FLORIDA

DEPARTMENT OF ENVIRONMENTAL REGULATION

TWIN TOWERS OFFICE BUILDING
2600 BLAIR STONE ROAD
TALLAHASSEE, FLORIDA 32301-8241

BOB GRAHAM
GOVERNOR

VICTORIA J. TSCHINKEL
SECRETARY

GENERAL PERMIT FORM FOR CLOSED-LOOP AIR CONDITIONING RETURN FLOW AND SWIMMING POOL DRAINAGE CLASS V INJECTION WELLS

In accordance with Chapter 403., F.S., and Rules 17-4.71 and 17-4.72, FAC, a general permit is granted provided the well is constructed and operated in accordance with the provisions of Rules 17-28.52 and 17-28.61, FAC.

Type of Well (check one):
Air conditioning return flow:_______ (Must be closed-loop with no provisions for additives)
Swimming pool drainage:______

Owners Name/Address:________________________
(Name)
____
(Street, P. O. Box, RFD#)
____
(City) (State) (Zip)

Operators Name/Address:________________________
(Name)
____
(Street, P. O. Box, RFD#)
____
(City) (State) (Zip)

Driller's Name:________________________

Drilling Company Name:________________________

Address: ________________________
(Street, P. O. Box, RFD#)
____
(City) (State) (Zip)

Phone Number:____________ License Number:____________

Well Information:

Total Depth:____________ Depth Cased:____________

Type of Completion:: Screened:__________ Open Hole:__________

Other (Specify):________________________

Location: Latitude:____°____'____" Longitude:____°____'____"

Township:________ Range:________ Section:____1/4____1/4____1/4

____

Location Map: (draw on back)
Well Construction Diagram: (draw on back)

DER FORM 17-1.209(10) New 5/8/85